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USDA United States Department of Agriculture

Forest Service

North Central Forest Experiment Station

General Technical Report **NC-191**

KNOWLEDGE FOR THE FUTURE OF BLACK WALNUT

Proceedings of the Fifth Black Walnut Symposium

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Each conference registrant was eligible for 13.5 hours of Continuing Forestry (CFE) offered by the Society of American Foresters for attending this conference.

North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
Manuscript approved for publication June 16, 1997
1997

KNOWLEDGE FOR THE FUTURE OF BLACK WALNUT

Proceedings of the
Fifth Black Walnut Symposium

Held at
Hammons Conference Center
Springfield, Missouri
and
Sho-Neff Plantation
Stockton, Missouri

July 28-31, 1996

Edited by
J. W. Van Sambeek

Sponsored by
Walnut Council
Hammons Products Company
School of Natural Resources - University of Missouri
North Central Forest Experiment Station - USDA Forest Service
Southwest Missouri Resource Conservation & Development Council
and
Missouri Department of Conservation

Endorsed by
Society of American Foresters

Published by
North Central Forest Experiment Station
USDA Forest Service

PREFACE

This symposium is the fifth in a series of symposia on the establishment, management, and utilization of black walnut. The first symposium, "Black Walnut Culture", was held in 1966 in Carbondale, Illinois. Its purpose was to make available to walnut growers "some ways to increase the growth and improve the quality of walnut timber." The second symposium, "Black Walnut as a Crop", also was held in 1973 in Carbondale, Illinois. Its purpose was to present state-of-the-art information on all phases of walnut culture. The third symposium, "Black Walnut for the Future", was held in 1981 in West Lafayette, Indiana. Their goal also was to "summarize current information on walnut to establish the direction for future research for the next several years." The fourth symposium, "The Continuing Quest for Quality", was held again in 1989 in Carbondale, Illinois. This symposium followed the past tradition of bringing together experts and walnut managers to discuss the current state-of-the-art knowledge on culture and utilization of black walnut. The fifth symposium continued this tradition by inviting experts knowledgeable in their respective fields to present current information and prepare papers for this proceedings. It was the goal of this symposium to provide a forum for the exchange of knowledge and ideas while identifying the opportunties for increased use of special forest products and expand opportunities for nut culture and agroforestry practices.

ACKNOWLEDGMENTS

This symposium was hosted by the staffs of Hammons Products Company; School of Natural Resources at the University of Missouri, University Center for Agroforestry; Missouri Department of Conservation; Southwest Missouri RC & D Council; Walnut Council; and the North Central Forest Experiment Station of the USDA Forest Service. The staffs of all seven organizations contributed immeasurably to the success of the symposium. The efforts of the Program Committee members and the helpful cooperation of Nancy Gunning and Rachel Van Sambeek are especially noteworthy. The enthusiastic support and encouragement of Dwain Hammons, President of Hammons Products Company and of Felix Ponder, Jr., President of the Walnut Council are gratefully acknowledged. Special thanks is given to Hammons Products Company and Sho-Neff Plantation for allowing us to use their semi-annual Field Day logo.

The Planning Committee would also like to express their appreciation to Larry Harper, Jack Slusher, Brian Brookshire, Dan Day, Larry Frye, Jim Jones, Bob Burke, and Jerry Van Sambeek for serving as session moderators. The high quality of the proceedings is a positive reflection on the dedication of those who served as manuscript reviewers. These include W. Clark Ashby, David C. Baumgartner, Walt Beineke, Todd Bowersox, Robert Burke, Ed Cesa, Robert Chenoweth, Mark E. Coggeshall, Larry R. Frye, Dave Funk, H. Gene Garrett, Mark Gibson, Paul Kormanik, Joe Lais, Manfred Mielke, Nadia E. Navarrete, John Phelps, Felix Ponder, John E. Preece, George Rink, Paul Roth, Dan Schmoker, Bob Seavy, Peter Somers, Archie Sparks, Doug Stokke, Jeff Stringer, Jerry Van Sambeek, Rachel Van Sambeek, Mike Vasievich, Jan Wiedenbeck, and Keith Windell. Last, but not least, the Planning Committee wants to give a special thank you to the men and women of the Walnut Council for your encouragement, support, and willingness to put into practice concepts discussed at these symposium.

REVIEW PROCEDURES

Each manuscript published in these proceedings was critically peer-reviewed by one or two scientists and one or two users with expertise in the area of the subject matter of the manuscripts. Reviews were returned to the senior author who revised the manuscript appropriately and resubmitted it vin electronic form for formatting and publication by the North Central Forest Experiment Station, USDA Forest Service. Manuscript authors are responsible for the accuracy of their papers. The mention of trade names, pesticides, fertilizers, and other chemicals within the articles does not constitute an endorsement by the U.S. Department of Agriculture or any of the sponsors of this symposium.

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BLACK WALNUT, AGROFORESTRY, AND NUT PRODUCTION

Senator Kit Bond[1]

A hearty welcome and greeting to those from near and far who have come to Missouri for the Walnut Council Meeting and Fifth Black Walnut Symposium. I thank the organizers for asking me to share some views with you, and I congratulate the Site Selection Committee for making the right choice. The Walnut Council has played a critical role since its formation in the late 1960's, in promoting black walnut and in furthering our understanding of this valuable species.

As a servant in government, I find one of the most invigorating things to be given is the opportunity to speak about something you actually know something about. Seriously, though, I look forward to being able to speak about something with which I have direct first hand knowledge and experience and appreciation. Staff has reported to me that I have an unofficial reputation as being the Senate's "tree nut". In the United States Senate, that's about as good a label as one could hope for.

I have planted black walnut trees on my property in Mexico, Missouri, and I know that they will be the best long-term investment I can make. Black walnut is the most valuable tree species in the U.S., and is an important component of eastern hardwood forests. Missouri is one of the leading states in wood production and leads the nation in walnut nut processing. Hammons Products Company in Stockton, Missouri, who I understand you will be visiting tomorrow, is the number one processor of black walnut meat.

I have reviewed the agenda for the coming days. I pay tribute to the many participants, but I want to specifically recognize Gene Garrett from the University of Missouri. Gene is a friend, advisor, pioneer, and "co-conspirator" in pursuit of advancing agroforestry in this nation. Thanks to the hard work of Gene and others attending this conference, I think we are making great strides in advancing the profile of agroforestry. Trying to promote a new idea in its infant stages is a formidable task, and I look forward to the challenges that lie ahead.

Agroforestry technologies, as most know, include windbreak systems, riparian buffer systems, streambank bioengineering, alley cropping, tree and pasture systems, waste disposal systems, and forest farming. From my perspective in Washington, where one side strenuously argues "X", and the other side argues "Y", agroforestry represents one of those rare opportunities where both sides can be satisfied. We have spent considerable time and energy over the previous years arguing how to promote good stewardship and conservation in a way that is not economically destructive to small businesses and landowners. Agroforestry actually holds the promise of offering clean air, clean water, and wildlife benefits with a financial incentive.

To advance this, we have secured authorization and appropriations for research. The 1990 Farm Bill created the National Agroforestry Center, and I have worked very hard with Senator Kerry from Nebraska in supporting the necessary funding to keep the program viable. Late last year, when the USFS cut their budget by over 50%, we called in the USFS Chief, and after 45 minutes, we got an extra 100,000 dollars of the cut restored to the program. It looks as though this year there will be no further cut to the program. Bill Rietveld, who heads up the center, has done a terrific job there, and is a forceful and knowledgeable proponent of agroforestry. Under Bill's direction, the center continues to do valuable research and coordinate important technical outreach efforts.

I have always been amazed that today's farmers, sophisticated enough to increase production year after year, who now use computers and Global Positioning Systems to apply chemicals, are gunshy when presented with the idea of planting some of their CRP ground, or other marginal ground, or riverine areas with trees such as black walnut. These farmers will say: "I don't know how to plant them." I am convinced that these people could grow anything they decide to

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[1] Senator Kit Bond, Russell Office Building, Room 267, Washington, DC 20510.

grow, and there is no reason they shouldn't be more involved in reforesting our countryside.

Gene works for the University of Missouri but spends a great deal of time working cooperatively with the Agricultural Research Service's, South Central Family Farm Research Center in Arkansas to develop a research and technology transfer program to provide additional income alternative opportunities for the family farm. Congress added a significant increase in funding for this project last year, and we think we can maintain that level this year. This year, we have also included language in the appropriations bill which funds the Environmental Protection Agency that urges them to incorporate agroforestry into their strategy to mitigate nonpoint source pollution. Furthermore, an agroforestry floodplain initiative has been discussed by the USFS to identify frequently-flooded areas in river bottoms where farmers now plant crops that are vulnerable to floods and replace crop production with agroforestry systems. I am very excited about this idea which has a heightened level of public and private benefits given the sensitive position in the watershed and the economic losses caused by flooding in recent years.

Last week in Washington, a follow up interagency meeting of the USDA's Sustainable Agriculture Working Group met to discuss the formation of specific ways to make agroforestry more visible within USDA and to discuss how to identify specific missions and sources of funding to promote agroforestry utilization. The group is made up of folks from EPA, ARS, U.S. Forest Service, the Natural Resources and Conservation Service, and the Cooperative State Research Education and Extension Service. I am very excited that we seem to be getting some traction on this issue. I think if we can keep at it, we can advance many of these concepts that are of mutual interest to us advocates. Concepts that will benefit the bottom line for property owners, provide valuable commodities to consumers at a competitive price, and improve our nation's environment. There are agroforestry provisions contained in three separate appropriation bills, and I urge each of you to continue to build upon the work that is already done to further advance this initiative.

Again, I welcome you to Missouri, and I thank you for this opportunity to speak. I regret that I have to join you by means of a videotape, but I look forward to hearing reports from the conference in the coming days.

FOREST SERVICE REFLECTIONS ON BLACK WALNUT RESEARCH

Richard V. Smythe[1]

Good morning. I am not Jerry Sesco, Deputy Chief for Research. Jerry is 1 or 2 in. taller than I. My position is Director of Forest Environment Research which means I have national responsibility for research in range, wildlife, fish, and water. At this point, you may well be asking yourself, "What do range, wildlife, fish, and water have to do with black walnut?" The short answer is "not much". But before you throw up your hands in complete bewilderment, let me explain why I am here today to welcome you on behalf of USDA Forest Service Research.

One reason that I am here is that Jerry Sesco could not be here. He had to be in Mexico. A second reason is that Carbondale and black walnut research have played a key role in 10 years of my Forest Service career. For 5 years I was an Assistant Director (AD) at North Central Forest Experiment Station, and I served another 5 years as Deputy Station Director. My Assistant Director job was AD South. Being AD South meant that I had responsibility for research at Carbondale, Illinois, and Columbia, Missouri. It also meant, mysteriously, that East Lansing, Houghton, and Marquette, Michigan, were my responsibility. But that is another story.

Both Carbondale and black walnut research were important components of my North Central Forest Experiment Station life. Carbondale was my biggest program, it had the most people, and was one of the nicest labs in all of Forest Service Research. Carbondale was where I attended my first buffalo troe. It was also the scene of my introduction to the Southern Illinois University Saluki basketball chant repeated with considerable enthusiasm and dubious tastefulness throughout the one game I attended with Dave Funk as my host.

Carbondale, black walnut research, Walnut Council—what a flood of associations and names. The Walnut Council, for example, has dedicated itself to providing a forum for encouraging the planting of walnut and exchanging of research information to facilitate transfer of science and technology from the research laboratory to field plantings. When I looked over your agenda for the next 3 days, I can tell your mission remains as strong as ever.

I also see that the USDA Forest Service personnel have remained valuable contributors to accomplishing your mission. Felix Ponder currently serves as your President. Looking at your quarterly bulletin, George Rink obviously takes great pride in serving as your Bulletin Editor. Jerry Van Sambeek and Manfred Mielke, respectively, serve as chairs for the Education and Protection Committees. I see one of our newest scientists, Doug Stokke, serves as your Federal Representative. I am also not surprised by how often names of retired USDA Forest Service Personnel come up anytime we discuss walnut research at Carbondale. It is obvious people like Burl Ashley, Dave Funk, Bob Phares, Craig Loesche, John Krajicek, Cal Bey, Bob Williams, Dick Schlesinger, Barbara Weber, and Bry Clark have made lasting contributions.

In thinking about research, I am reminded of the comments made by Jerry Sesco in his 1989 keynote address at the fourth Black Walnut Symposium. He suggested that research tends to pass through three stages. The first stage is the start-up phase, the second stage is one of rapid growth, and the third stage is a mature phase.

In his 1989 presentation, Jerry suggested the first stage of walnut research occurred as long ago as the 1930's. The second phase of walnut research probably began in the late 1960's and early 1970's and continued until the mid to late 1980's. This phase was characterized by an expanded interest in black walnut research by university and federal scientists. During these years, walnut research programs and budgets expanded, new scientists began work in new areas, and rapid progress was made in the areas of plantation establishment and management of young trees. We now believe walnut research

[1] Richard V. Smythe, Director, Forest Environment Research, USDA Forest Service, 20114th Street, S.W. at Independence Ave., S.W., Washington, DC 20250.

has entered the mature phase in which many of the critical questions have been addressed and have been answered.

So why the recent reductions in the walnut research program? Part of the answer lies in our assessment of the maturity of the research. The rest of the answer lies in a broader perspective. The reductions reflect a nationwide retrenchment in research dollars due to large increases in the Federal deficit and concerns for a balanced budget. We have had to make some hard choices. We have had to reduce some of our research. We have had to eliminate some of our research. I'm not going to run a bushel of numbers by you but all of us must understand the change has been significant. Just two examples—we've gone from a high of 972 scientists a number of years ago to under 600 by the end of this year, a reduction of almost 40%. This year's budget is down $22 million from the initial budget of 1995. Business as usual is impossible.

But I don't wish to dwell on the negative. Last week I was in Montana and saw the following notice posted on the wall of a Forest Service office, "No one ever had a rainbow without a little rain." Let's concentrate on the rainbow.

Thoughtful people can disagree on research priorities. Mature people disagree without becoming disagreeable. We, Forest Service Research, acknowledge a continuing obligation to growers of black walnut. I urge you and our Columbia, Missouri, hardwood silviculture lab headed by Frank Thompson to develop a working partnership as we all work toward an orderly close down of Carbondale and a responsible transition of selected work to Columbia.

I am pleased to join you at the Fifth Black Walnut Symposium and the 27th annual meeting of the Walnut Council. During or after this meeting if you have questions or concerns, please ask. We need your advice, we welcome your counsel, and we solicit your partnership as we establish the future direction of USDA Forest Service Research. Again, thank you for the invitation to be here.

SEEKING A VISION FOR THE FUTURE

Larry R. Frye[1]

ABSTRACT.—A report summarizing the discussions at the Seventh American Forest Congress which was held in Washington, DC on February 20-24, 1996. Nearly 1,500 participants from across the U.S. met to develop a new vision statement and set of principles for the management of our nation's forests. Of the participants, those from the environmental/preservationist side of the issues comprised the largest block at 567, with the forest industry at 327, and public agency personnel at 258. Academia and the scientific sector had 167 participants, 90 tree farmers and 81 college and high school students were also present. The purpose of the Seventh Congress was to find a common ground on the many issues facing forestry in America. Landowner rights and responsibilities were a major topic of the five day event.

A HISTORICAL LOOK AT AMERICA'S FOREST CONGRESSES

Since 1882, the nation has on six previous occasions gathered its leaders in forestry, conservation, and the environmental fields to sit down and trade ideas and establish goals and plans for the future of America's forests. The previous Forest Congresses somewhat tell the story of forestry in America.

FIRST AMERICAN FOREST CONGRESS

In 1882, America convened its first Forest Congress. At the time, there was only one professionally trained forester working in the United States—the German immigrant Bernard Fernow. At the time, the public policy of the United States was to dispose of the public domain just as fast as possible to settlers, ranchers, the railroads, and to industry. Forests were being cleared rapidly for farms and towns. But concerns were growing about forest devastation and timber famine. The First Congress helped consolidate the forestry movement in the United States.

SECOND AMERICAN FOREST CONGRESS

By the time of the second Forest Congress in 1905, 23 years after the first Congress, the climate had changed radically. The nation was shocked at the wide-scale land frauds. Federal investigations resulted in convictions and prison sentences for many public officials. Many of the top colleges in the country were offering courses in forestry. In 1900, the Society of American Foresters was founded by Gifford Pinchot. Millions of acres of western lands had been set aside in forest reserves. President Theodore Roosevelt gave the keynote address, and a reception was held in the White House. The week-long session ended with the approval of 18 resolutions. Among them was a plea to all state authorities for the enactment and enforcement of laws for the protection of forests from fire and for reducing the burden of taxation on lands held for forest reproduction. It also called for the formation of eastern forest reserves. Within months the U.S. Forest Service was formed with Gifford Pinchot as the first Chief.

THIRD AMERICAN FOREST CONGRESS

In 1946, the nation was coming out of a catastrophic worldwide conflict that had made unprecedented demands on the world's forest resources. Ahead lay the rebuilding of a devastated Europe and Asia. In America, millions of young veterans were returning home, eager to

[1] Larry R. Frye, Executive Director for the Fine Hardwood Veneer Association, American Walnut Manufacturers Association, and Walnut Council, 260 South First Street, Suite 2, Zionsville, IN 46077.

find housing and start families. The purpose of the Third Congress in October 1946 was to (1) dramatize to the American people the condition of their forest resources after 4 years of war, (2) to bring together representatives of government, industry, agriculture, labor, and the public for joint consideration of the forest situation, and (3) to enlist the aid and support of all citizens interested in the preservation and use of forests in formulating a national program of forestry.

Clinton Anderson, Secretary of Agriculture, gave the opening address and emphasized that our forest problems cannot be overcome unless effective, forceful action on a national scale is undertaken to make and keep private forests productive. He went on to say, "Increasing pressure is being brought to bear upon the Forest Service to over cut. Except for a limited and brief excursion beyond sustained yield in this housing emergency, I shall support adherence to sustained yield principles." Everyone at the Third Congress agreed public education was needed, but they could not reach a consensus on the question of federal regulation.

FOURTH AMERICAN FOREST CONGRESS

In 1953, the Fourth American Forest Congress was convened. The 1950's were growing times. Housing starts were soaring, Forest Service timber sales were setting new highs almost every year, and industrial forestry was beginning to gain some respect. This Congress was unique in that it had on the program the President of the United States, his Chief of Staff, the Secretary of Agriculture, and the Secretary of the Interior. Also, this was the first Congress that had women on the program. The Fourth Congress did not stimulate any immediate policy changes, but it did, for a while at least, dispel much of the distrust between public and private forestry.

FIFTH AMERICAN FOREST CONGRESS

The Fifth American Forest Congress was held in October 1963. The 1960's saw the beginnings of the environmental movement that culminated in the 1970's with Earth Day and a flood of federal legislation. In 1962, Rachel Carson's book Silent Spring was published. Forests were being looked at for more than wood by an increasingly urbanized society. The Fifth Congress was the first to devote any attention to products other than timber. Shortly after the Congress, the Public Land Law Review Commission was established.

SIXTH AMERICAN FOREST CONGRESS

The 1970's were turning the forestry world upside down. Forestry was under attack in the courtrooms and in the press. A flood of environmental legislation came out of the U.S. Congress. It was the Greening of America and the mix of environmentalism, counter-culture, alternative lifestyles, and the questioning of the establishment by much of the country's youth ran head-on into what had been accepted forest management practices. The Sixth American Forest Congress was held in October 1975. It was not entirely a response to these new challenges. It was called to mark the 100th Anniversary of the American Forestry Association. World forestry was in the discussions.

SEVENTH AMERICAN FOREST CONGRESS

The Seventh American Forest Congress was held on February 20-24, 1996 in Washington, DC. As it was at the time of the Sixth Congress, traditional forestry was being challenged from every direction. Timber sales on all the National Forests were virtually at a stand-still. The preservationist groups were out to prohibit logging on all federally owned public lands, to eliminate the so-called below-cost timber sales, and to push for a policy of no management in roadless areas. The organizers of the Congress hoped to be able to chart a positive, new direction for America's forests. The ultimate purpose of the Seventh American Forest Congress was to develop a common vision among the fighting groups and see if they could agree upon a set of principles that could guide the management of America's forests well into the next century. The Seventh Congress hoped to develop a series of positive steps, or actions, that could produce better forest management policy.

Each day presented intense, and sometimes heated, discussions among the mixture of interests comprised of woodland owners, conservationists, forest scientists, industry officials, academicians, and the full range of environmentalists. Some of the environmentalists came to the opening session late purposely to disrupt the start of the Congress. They openly argued each point, protested the views expressed by others, demonstrated at will, and in some instances walked out of the proceedings. In the end common sense seemed to prevail, but time will tell.

SEEKING A VISION FOR THE FUTURE

Seven vision elements were brought to the Congress for consideration from the series of 50 round table discussions held over 9 months around the country. After a day and a half, the original 7 elements were expanded to 13. In some instances some of the original seven tried to cover to much and were divided into separate elements. A lot of "word-smithing" was done in an attempt to satisfy the wide variety of interests represented at the Congress. Because of the sensitivity and the emotion of the issues, the final report of the Congress will likely contain all 13 elements. It is also likely the results of the vote tally will also somehow be incorporated into the report. A green vote is for acceptance of the statement. A red vote is against, and a yellow vote is generally in favor with some objection to certain wording.

VISION ELEMENTS WORKING DOCUMENT

Vote Tally [Green Yellow Red]			**Vision Elements**
[85%	10%	5%]	1. In the future our forests will be maintained and enhanced across the landscape, expanding through reforestation and restoration where ecologically, economically, and culturally, appropriate, in order to meet the needs of an expanding human population.
[75%	18%	7%]	2. In the future our forests will be sustainable, support biological diversity, maintain ecological and evolutionary processes, and be highly productive.
[88%	8%	4%]	3. In the future our forests will sustainably provide a range of goods, services, experiences and values that contribute to community well being, economic opportunity, social and personal satisfaction, spiritual and cultural fulfillment, and recreational enjoyment.
[90%	7%	3%]	4. In the future our forests will be held in a variety of public, private, tribal, land grant, and trust ownerships by owners whose rights, objectives, and expectations are respected and who understand and accept their responsibilities as stewards.
[84%	11%	5%]	5. In the future our forests will be shaped by natural forces and by human actions that reflect the wisdom and values of an informed and engaged public, community and social concerns, sound scientific principles, local and indigenous knowledge and the need to maintain options.
[70%	14%	7%]	6. In the future our forests will be managed consistent with strategies and policies that foster forest integrity and maintain a broad range of ecological, economic and social values and benefits.
[67%	21%	12%]	7. In the future our forest will be acknowledged as vital by citizens who are knowledgeable and involved in stewardship and who appreciate the contribution of forests to the economic and environmental quality of life.
[34%	31%	35%]	8. In the future our forests will provide a sustainable level of products and benefits that satisfy society's needs because contributions from more efficient utilization, recycling, and other efforts reduce consumption.
[69%	17%	14%]	10. In the future our forests will maintain their essential role in protecting watersheds and aquatic systems.
[89%	6%	5%]	11. In the future our forests will be enhanced by policies that encourage both public and private investment in long-term sustainable forest management.
[74%	16%	10%]	12. In the future our forests will contribute to strong and vital rural and urban communities that benefit from, protect and enhance the forests in their vicinity.
[54%	19%	27%]	13. In the future our forests will be managed on the basis of a stewardship ethic with respect, reverence, and humility.

A similar exercise was conducted to attempt to come up with some common principles. The Congress began its work with 16 draft principles that had come from the grass roots in the round tables. During the discussion, the environmental faction and other interest groups were successful at injecting 45 more items to the list. Many were considered statements rather than principles, but they had to be allowed to work through the process.

CONCLUSION

History will probably look favorably on the Seventh American Forest Congress. It may well be remembered as the Congress that brought common sense back to the forestry arena. The word management was once again a respectable term. The property rights and the associated responsibilities theme was perhaps the most prevalent single issue. Federal government interference in local affairs was identified as a strong concern.

The older generation at the Congress became more comfortable with the buzz words of the newer generation. The cry for a nonviolent approach to problem solving was heard, loud and clear. There was a strong move to find common ground. There will still be individual hang-ups, hidden agendas, and attacks on the way federal, state, and even private lands are managed. However, as a result of the Seventh Congress, America may see a return to majority rule when it comes to finding ways to manage a tract of forest land in the future.

STATUS OF BLACK WALNUT IN THE UNITED STATES

Thomas L. Schmidt and Neal P. Kingsley[1]

ABSTRACT.—Data related to area of timberland with black walnut (*Juglans nigra* L.) present as well as black walnut volume, growth, mortality, and removals are presented. Results indicate more than 15.4 million acres of timberland with black walnut present, 95% of which is privately owned. In the most recent inventories, 58% of the black walnut timberland was classed as sawtimber. Growing-stock volume increased from 1.0 billion cubic feet in 1963 to more than 1.8 billion in 1989. Sawtimber volume increased from 2.7 billion board feet to 4.9 billion in the same time period. The overall future for black walnut appears bright, the number of black walnut trees has been consistently increasing and there has been an average increase in growing-stock volume of more than 22 million cubic feet per year.

INTRODUCTION

Black walnut (*Juglans nigra* L.), one of the most highly valued hardwood species, is found throughout most of the eastern half of the United States (Harlow and Harrar 1969). Black walnut is associated with a number of forest types, but is most frequently found in mixed forests on moist alluvial soils (Williams 1990). The species is not dominant in most forests, but rather is generally found as scattered single trees or as small isolated groups within hardwood stands (Fischer 1982). Black walnut has a large geographical range but a narrow range of suitable sites where it can grow at an adequate rate.

Since the late 1800's, the supply of black walnut has been a topic of concern. The concern for black walnut has been centered around high quality, large diameter trees but the overall supply of black walnut has also received considerable attention. In 1880, a Purdue University professor reported that about 85% of the black walnut resource in Indiana had been disposed of (Frye 1982). In 1966, a Forest Service Silviculturist stated that large-diameter, high-quality veneer and sawlogs were in critical shortage (Boyce 1966). Foresters concerned about the supply of black walnut have historically urged an increase in the management and planting of black walnut (Quigley and Lindmark 1966, Adams 1981). In an address to the Third Black Walnut Symposium, R. Max Petersen recognized that while, for most hardwoods, growth significantly exceeded demand, the situation was quite the opposite for black walnut (Petersen 1982). He estimated that demand for black walnut had been greater than supply for many years and that the gap between demand and supply was projected to widen at an ever increasing rate.

Inventory results from the 1970's seemed to confirm the concerns expressed by forest industries, foresters, and landowners. For example, in Missouri black walnut growing stock decreased from 100 million cubic feet in 1959 to 97 million cubic feet in 1972, and sawtimber decreased from 238 million board feet to 217 million board feet in the same time period (Spencer and Essex 1976). In Iowa, black walnut growing-stock volume decreased by more than a third from 1954 to 1974, going from about 52 million cubic feet to about 32 million cubic feet (Spencer and Jakes 1980). In the same time period, sawtimber volume in Iowa was reduced by more than half, decreasing from 188 million board feet to 88 million board feet. Similar examples of decreasing black walnut volumes in the 1960's and 1970's could be provided for many other states.

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Plantations have been viewed as a means to increase the supply of black walnut. However, because of the time period required to see a plantation through from seedling to sawtimber, the large investment required by the landowner in both time and money, the strict site requirements needed for adequate growth, and many other factors inherent in the production process, plantations of black walnut have not met the expectations of either the producing landowners or the utilizing industries. As a result, we feel that the vast majority of the future black walnut timber supply will come from natural stands.

In light of the many concerns about black walnut, it is important to understand and evaluate black walnut's current status. In this paper, we use the most recent forest inventory information to determine the current supply and demand for black walnut and compare our findings to historical estimates (Quigley and Lindmark 1965).

METHODS

Data for this paper are from the USDA Forest Service, Forest Inventory and Analysis' (FIA) Eastwide Data Base (EWDB) which contains the most recent statewide forest inventory for each state (Hansen *et al.* 1992). We also used FIA resource bulletins from both previous and most recent inventories of each state to estimate change over time. Of the 30 states where FIA recorded black walnut on timberland, we focused on 12 states based on the amounts of black walnut area and volume in those states. In addition, states in the USDA Forest Service, North Central Forest Experiment Station's Region with black walnut present received additional attention due to the availability of additional data.

Data presented pertain only to timberland, however, more than 95% of the forest land in the United States is classified as timberland (Powell *et al.* 1993). Timberland is forest land that is capable of producing more than 20 cubic feet per acre per year of industrial wood crops under natural conditions. In addition, the forest land must not be withdrawn from timber utilization. There are other classifications of forest land that contain black walnut, including reserved forest land, wooded strips, and pasture land with trees that do not meet the timberland definition. We recognize that significant amounts of black walnut occur on these non-timberlands and that they make important contributions to not only the timber supply of black walnut, but also to wildlife and other forest related benefits. However, until recently, FIA did not install field plots on these other lands. As a result, data are very limited for forest land classifications other than timberlands and are, therefore, not included in this study.

The amount of black walnut on non-timberland has been estimated to range from 5 to 25% of that found on timberlands. The percentage varies, depending on the predominant land-uses in each state. In states with a high percentage of land that is annually cultivated, the amount of black walnut on non-timberland is usually lower when compared to a state with a higher percentage of land in non-cultivated uses such as pasture.

Black walnut is not a recognized forest type but is included within several forest types. Black walnut is a common associate of five forest cover types and is also found as an occasional associated species in four other forest cover types recognized by the Society of American Foresters (Williams 1990). Area data are generated from FIA tree-level records and are based on the existence of at least one 5 in. d.b.h. (diameter at breast height) or larger black walnut within an established FIA field plot. Area data for each state in the black walnut range are generated by this method for ownership, stand-size class, and site productivity class. For stand-size class determinations, sawtimber sized stands are stands with half or more of the total live tree stocking in trees that are at least 11 in. d.b.h. Volume, number of trees, growth, mortality, removals, and change over time are generated from the EWDB and FIA resource bulletins.

Volume is discussed as either growing-stock or sawtimber volume. Growing-stock volume is the net volume in cubic feet of growing-stock trees 5.0 in. d.b.h. and over, from 1 ft above the ground to a minimum 4 in. top diameter outside bark (d.o.b.) or to the point where the central stem breaks into limbs. Sawtimber volume is the net volume in board feet (International 1/4-inch rule) of the saw-log portion of live sawtimber sized trees from 1 ft above ground to a minimum 9 in. top d.o.b. Sawtimber volume is a subset of growing-stock volume. Growing-stock volume, growth, removals, and mortality are used when

the overall resource is being described and for most ecological based studies. Sawtimber volume can be converted to growing-stock volume. However, growing-stock volume cannot be converted to sawtimber volume because it contains trees that are not of sufficient size to qualify as sawtimber (those trees more than 5 in. and less than 11 in. d.b.h.). For more information concerning FIA methodology, consult the Appendix section of the resource bulletins cited in this paper.

Dates of the most recent statewide inventories range from 1981 in Kansas to 1993 in Michigan. To determine the average most recent FIA inventory date for black walnut, the inventory year for each state was multiplied by the percent of the total national growing-stock volume represented by each state. This resulted in an average inventory date of 1989. By comparison, Quigley and Lindmark referenced the 1962 appraisal of the timber resources of the United States. Thus, comparisons over time are based on average inventory dates of 1962 and 1989, a 27 year time span. No comparisons to previous inventories or publications are made concerning area of forest land with black walnut present because prior to this paper, to the knowledge of the authors, no estimate of the acreage of forest land with black walnut present had been made.

To estimate the volume of timber produced from timberland, FIA units conduct direct mail canvasses of the mills that process the timber. These surveys, called Timber Product Output (TPO) studies, include all of the volume of logs and bolts that are processed. There are two sources of black walnut timber products; those from timberland and those from lands not considered timberland such as nonforest area with trees, fence rows, and other lands. For trees harvested from timberland, products are said to come from the growing stock portion of the tree and also from the non-growing stock portion of the tree. Non-growing stock removals include the stump, limbs, tops above 4 in., and cull sections of the main bole. Also included are volumes from non-growing stock trees which include rough and rotten trees, dead trees, and trees grown on non-timberland areas. Thus, it is conceivable that the total volume of products removed can exceed the total volume of growing stock removed.

The difference in harvested tree volume and product volume results in either logging residues (the unutilized growing stock portions of growing-stock trees) or logging slash (the unused portions of non-growing stock portions of growing-stock trees). All timber product output plus harvest residues and slash equal the total wood material cut from all sources. The growing stock portion of timber product output plus logging residues equals the growing stock removals from the growing stock inventory. If the total volume harvested was significantly greater than the growing-stock volume removed, it can be assumed that a significant volume was produced from non-growing stock sources. This is often the case for black walnut since in many areas a significant volume of material is found on non-timberland areas and in some areas a considerable volume of material from non-growing stock portions of growing-stock trees is utilized.

The amount of volume extracted from the round log varied, depending on the type of product, the efficiency of the mill, and the quality of the log. Standard volume, measured in board feet, was the actual volume in the harvested log utilized for a specific product, generally saw logs or veneer logs. The ratios for current sawtimber board foot volume to growing-stock cubic foot volume used in this study are based on logging utilization studies conducted by North Central FIA during the most recent forest land inventories of each state in the region.

RESULTS

AREA

The most recent inventories indicate more than 15.4 million acres of timberland with black walnut present (Table 1). Of the 15.4 million acres, 99% occurred in natural stands and 1% was in plantations. Black walnut plantations generally are small, scattered acreages. Ohio, Kentucky, and Illinois had the most acreage of black walnut in plantations.

While there are 30 states with naturally occurring black walnut, the walnut resource is not evenly distributed. For example, 50% of the total timberland area in the United States with black walnut occurred in only 4 states—Missouri,

Table 1.—Area of timberland with black walnut by ownership class

State	Most recent inventory	Ownership class						
		Total	National forest	Misc. federal	Other public	Forest industry	Private individual	Private corporation
		Thousand acres						
Missouri	1989	2,569.7	101.1	76.0	50.9	8.3	2,124.3	209.1
Kentucky	1988	1,971.2	46.1	-	15.5	10.3	1,770.3	129.0
Ohio	1991	1,759.8	26.8	-	46.6	19.0	1,532.3	135.1
West Virginia	1989	1,357.8	4.6	7.2	22.1	54.9	1,103.7	165.3
Tennessee	1989	1,234.6	7.7	36.2	11.5	59.7	1,088.3	31.2
Indiana	1986	1,064.2	12.9	31.4	27.5	1.9	907.6	82.9
Illinois	1985	941.5	20.1	-	15.8	4.0	853.1	48.5
Pennsylvania	1989	708.7	-	5.3	5.8	5.5	636.0	56.1
Virginia	1991	577.5	15.8	13.5	10.8	15.2	461.4	60.8
Iowa	1990	536.0	-	6.1	17.9	-	484.5	27.5
Kansas	1981	472.7	-	15.3	1.0	3.4	427.3	25.7
Arkansas	1988	451.4	52.0	6.3	6.2	9.7	343.8	33.4
18 other states		1,769.7	6.6	38.1	82.2	69.3	1,468.3	105.2
Total all states		15,414.8	293.7	235.4	313.8	261.2	13,200.9	1,109.8

Kentucky, Ohio, and West Virginia (Fig. 1). Twelve states accounted for almost 90% of the total area of timberland with black walnut present. Most of the states with large acreages of black walnut are in the Central Hardwood Region.

Comparing the area of timberland with black walnut present to the total area of timberland, Kansas ranks first with almost 40 percent of its timberland having black walnut present. Kansas is followed by Iowa, Indiana, Illinois, Ohio,

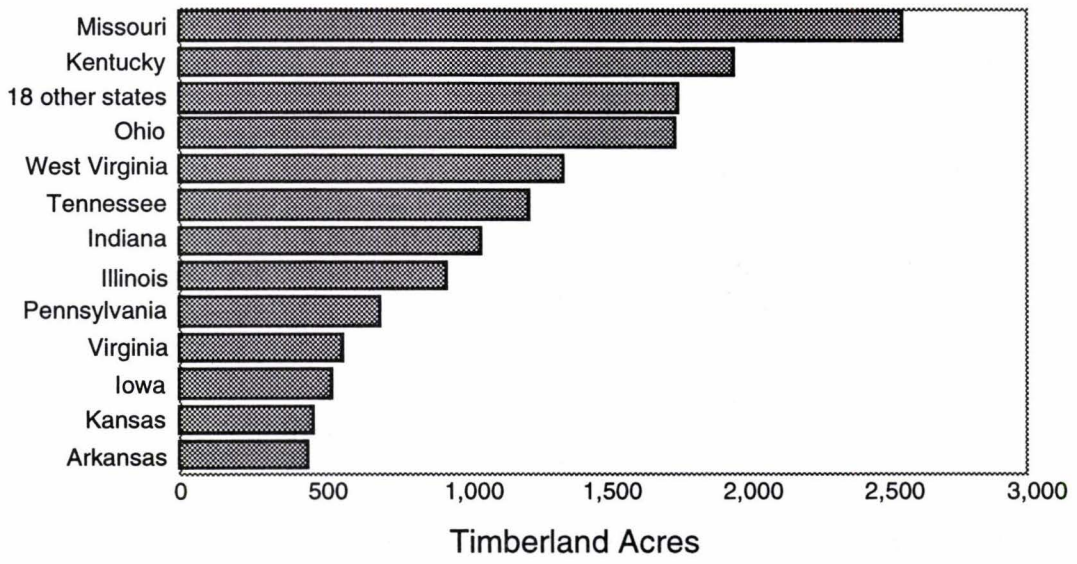

Figure 1.—Area of timberland with black walnut present from most recent inventories, by state.

Missouri, Kentucky, West Virginia, and Nebraska. In these states, at least 10% of the total timberland acreage contains black walnut. By comparison, Pennsylvania was 8th in total area of timberland with black walnut (709 thousand acres) but this was less than 5% of the total timberland area (15.9 million acres).

Individuals own 86% of the timberland area with black walnut present (13.2 million acres). Corporations, accounting for 7% (1.1 million acres), were the second largest ownership group. Forest industries owned only 2% of the timberland area with black walnut present. In total, the private sector represented 95% of the black walnut timberland area. These percentages were relatively consistent from state-to-state.

In the most recent inventories, 58% of the timberland with black walnut was in sawtimber-sized stands, 28% was in poletimber-sized stands, and 14% was in sapling-seedling sized stands (Fig. 2). All 30 of the states had the most timberland area with black walnut present in the sawtimber-size class (Table 2). These data represent the average stand size determined from the dominant trees in the stand, black walnut might or might not have been the dominant trees. However, since black walnut seedlings are intolerant of shade and are seldom found under dense tree canopies (Williams 1990), the black walnut size class should be similar to that of the overall stand.

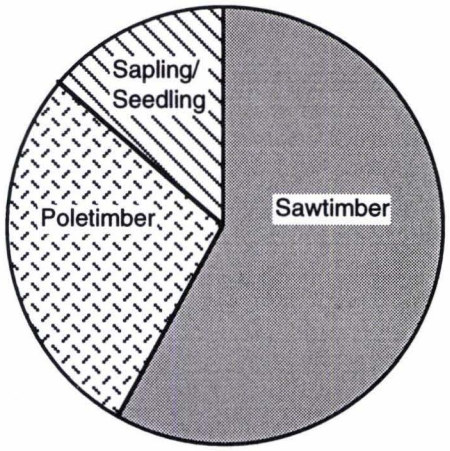

Figure 2.—Size class distribution of timberland area with black walnut present.

Table 2.—Area of timberland with black walnut by stand-size class

State	Total	Stand-size class		
		Sawtimber	Poletimber	Sapling-seedling
		Thousand acres		
Missouri	2,569.7	1,293.8	875.4	400.5
Kentucky	1,971.2	1,041.4	648.6	281.2
Ohio	1,759.8	1,012.3	420.1	327.4
West Virginia	1,357.8	774.1	442.8	140.9
Tennessee	1,234.6	659.8	401.3	173.5
Indiana	1,064.2	749.7	176.2	138.3
Illinois	941.5	668.0	173.1	100.4
Pennsylvania	708.7	400.1	236.4	72.2
Virginia	577.5	389.5	143.0	45.0
Iowa	536.0	390.1	107.7	38.2
Kansas	472.7	234.2	113.4	125.1
Arkansas	451.4	196.5	186.6	68.3
18 other states	1,769.7	1,130.9	437.7	201.1
Total all states	15,414.8	8,940.4	4,362.3	2,112.1

Table 3.—Area of timberland with black walnut by site productivity class

State	Total	Productivity class (cubic feet of growth per acre per year)				
		165+	120 -164	85 -119	50 -84	20 -49
			Thousand acres			
Missouri	2,569.7	15.4	28.9	207.9	1,289.0	1,028.5
Kentucky	1,971.2	-	149.9	353.6	605.8	861.9
Ohio	1,759.8	-	58.9	159.9	405.5	1,135.5
West Virginia	1,357.8	-	139.3	404.3	362.6	451.6
Tennessee	1,234.6	52.3	184.0	316.6	485.1	196.6
Indiana	1,064.2	-	206.1	449.6	298.4	110.1
Illinois	941.5	-	47.5	382.8	408.5	102.7
Pennsylvania	708.7	-	65.7	107.9	198.4	336.7
Virginia	577.5	4.6	15.1	158.4	356.3	43.1
Iowa	536.0	3.2	5.8	181.1	260.6	85.3
Kansas	472.7	-	2.1	67.4	220.5	182.7
Arkansas	451.4	4.8	0.0	40.0	280.3	126.3
18 other states	1,769.7	117.2	183.5	539.6	670.4	259.0
Total all states	15,414.8	197.5	1,086.8	3,369.1	5,841.4	4,920.0

Almost 70% of the black walnut timberland acreage was located on the two lowest productivity classes (Table 3). Less than 10% of the black walnut timberland was classified as being on sites with very high to excellent productivity potential. However, there were a few states with significant acreages of black walnut timberland on the higher productivity sites. For example, more than 60% of the black walnut timberland in Indiana was located on sites with a potential productivity of at least 85 cubic feet per acre per year.

NUMBER OF TREES

In the most recent inventories, there were almost 500 million black walnut growing-stock trees in the United States (Table 4). More than 90% of these trees were located in 12 states. The top 12

Table 4.—Number of black walnut growing-stock trees by diameter class

State	Total	Diameter class (inches d.b.h.)					
		1.0 -4.9	5.0 - 8.9	9.0 - 12.9	13.0 - 16.9	17.0 - 20.9	21.0 +
				Thousand acres			
Kentucky	94,453	70,875	14,854	6,507	1,732	410	75
Ohio	76,552	58,244	9,770	5,386	2,408	669	76
West Virginia	63,123	50,553	7,020	3,541	1,544	394	71
Pennsylvania	57,385	46,210	7,051	2,528	1,221	297	77
Missouri	50,936	33,580	9,860	5,417	1,668	376	36
Illinois	26,397	14,548	7,339	2,904	1,240	270	97
Indiana	22,715	11,900	5,686	3,208	1,489	375	56
Kansas	20,969	13,163	4,430	2,406	756	173	41
Iowa	13,677	8,238	2,351	1,920	867	272	29
Virginia	11,413	3,254	3,501	3,000	1,233	335	90
Tennessee	10,732	1,669	4,532	3,242	1,065	194	30
Michigan	7,968	3,470	2,494	1,343	468	160	34
18 other states	43,306	22,064	11,769	6,670	2,083	566	154
Total all states	499,625	337,768	90,657	48,071	17,773	4,491	865

states in terms of number of black walnut growing-stock trees were the same as those for timberland area with black walnut present, with the exception of Michigan which replaced Arkansas.

In addition to the half billion black walnut growing-stock trees, there were 91 million non-growing-stock black walnut trees (typically rough or rotten trees classified as cull) on timberland in the most recent inventories. Estimates of the number of black walnut trees on non-timberland run as high as an additional 125 million trees. Thus, in total, there were up to an estimated 716 million black walnut trees in the United States as of the most recent inventories.

Of the half billion black walnut growing-stock trees, two-thirds were less than 5 in. d.b.h. In the most recent inventories, only 8% of the total number of black walnut growing-stock trees were larger than 11 in. d.b.h., considered the minimum size necessary for being classified as sawtimber. Only 1% (5.4 million) of all of the black walnut growing-stock trees in the United States were larger than 17 in. d.b.h.

Kentucky, with almost 95 million trees, had the greatest number of black walnut growing-stock trees, almost 20% of the total number of black walnut growing-stock trees in the Nation. Ohio, West Virginia, Missouri, and Pennsylvania all had more than 50 million black walnut growing-stock trees.

The number of black walnut trees has been increasing. In Missouri, the number of black walnut trees increased from about 20.5 million in 1972 to more than 50 million in 1989. In Iowa, the number of black walnut trees doubled from 1974 to 1990, increasing from 6.7 million to 13.6 million. Similar increases occurred in most of the other states. Although increases occurred in all diameter classes, the majority of the increase in number of black walnut trees was in the smaller diameter classes.

VOLUME

In 1962, there were more than 1 billion cubic feet of black walnut growing-stock volume on timberland in the United States, 41% of which was sawtimber volume (Quigley and Lindmark 1966). In the most recent inventories, there were almost 1.6 billion cubic feet of black walnut growing-stock volume, 41% of which was sawtimber (Table 5). This was a 60% increase in total volume from 1962 to 1989, representing an average increase of about 22 million cubic feet per year. Interestingly, the ratio of sawtimber volume to growing-stock volume remained about the same between the two time periods.

Table 5.—Volume of black walnut growing stock by diameter class

State	Total	Diameter class (inches d.b.h.)								
		5.0- 6.9	7.0- 8.9	9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21+
		Million cubic feet								
Ohio	183.6	13.5	21.2	29.1	36.0	36.4	18.0	15.4	10.0	4.2
Kentucky	183.3	19.6	33.2	42.7	27.4	22.8	17.5	11.7	3.6	5.0
Missouri	147.5	11.9	22.4	29.6	26.6	24.5	14.4	11.1	4.8	2.3
Indiana	127.2	7.4	17.1	19.0	23.0	19.8	21.3	10.2	5.9	3.5
West Virginia	123.7	9.7	16.7	22.4	19.9	23.2	13.5	9.8	4.5	4.0
Illinois	119.1	11.5	18.5	16.7	22.7	20.7	11.7	7.9	3.7	5.7
Virginia	115.2	4.1	10.0	21.1	18.3	23.2	11.4	6.3	12.5	8.3
Pennsylvania	100.5	9.5	16.5	13.9	16.1	17.3	10.6	7.2	4.7	4.8
Tennessee	91.3	6.2	11.4	19.3	17.8	14.9	11.3	4.2	3.8	2.3
Iowa	63.8	2.9	4.6	9.4	12.0	13.0	7.7	6.2	5.9	2.2
Kansas	58.4	7.9	6.0	9.6	11.0	8.0	5.9	4.6	2.0	3.4
Michigan	54.4	4.4	6.4	9.4	9.5	8.4	5.7	5	2.9	2.9
18 other states	220.1	14.6	31.3	42.4	40.3	29.3	28.3	14.5	9.6	9.7
Total all states	1,588.1	123.2	215.3	284.6	280.6	261.4	177.2	114.0	73.7	58.1

In addition to the black walnut volume found on timberlands, there are large quantities growing in pastures, narrow wooded strips, and other areas not classified as timberland. As previously mentioned, these areas are not included in the volume estimates but they do contribute to the overall supply of black walnut in the United States.

Only 8% of the total growing-stock volume in the United States was in diameter classes larger than 19 in. d.b.h. The majority of the growing-stock volume was in diameter classes from 9 to 15 in. d.b.h., reflecting a resource that has the potential to greatly expand its volume, assuming these medium sized trees continue to mature (Fig. 3). If market pressures increase to where smaller sized sawtimber trees are harvested, the potential for greatly increasing the volume will be diminished.

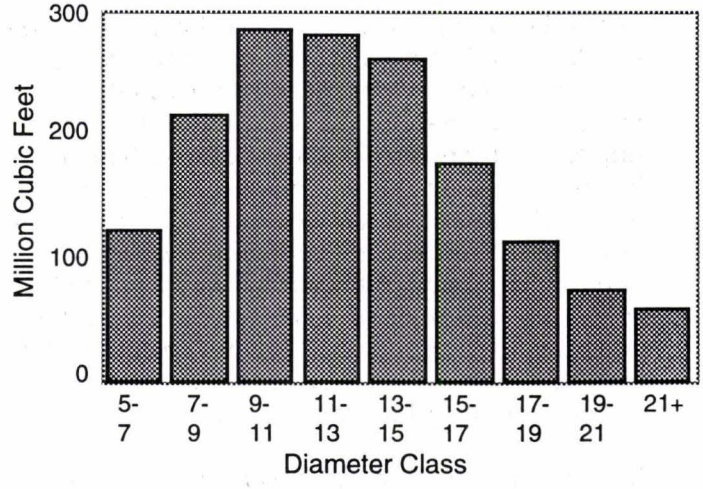

Figure 3.—Black walnut growing-stock volume by diameter class.

Ohio and Kentucky had the most black walnut growing-stock volume, each with about 183 million cubic feet (Table 5). These two states accounted for almost one-fourth of the total black walnut growing-stock volume in the United States. While these two states had similar totals, they differed in diameter class distribution. Ohio tended to have more volume in trees 11 in. d.b.h. and greater while Kentucky had more volume in trees less than 11 in. d.b.h. which is in agreement with the diameter class distribution shown in Table 4.

In 1962, there were an estimated 2.7 billion board feet of black walnut sawtimber (Quigley and Lindmark 1966). As of 1989, there were 4.3 billion board feet of black walnut sawtimber (Table 6). Over the 27 year period between the two estimates, black walnut sawtimber volume increased by almost 70%, averaging an increase of about 59 million board feet per year.

In addition to the sawtimber volume, there are many black walnut trees that are considered "short-log" trees and are not included in the

Table 6.—Volume of black walnut sawtimber by diameter class

State	Total	Diameter class (inches d.b.h.) 11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21+
		Thousand board feet International rule					
Ohio	510,820	143,700	155,297	82,845	65,743	43,858	19,377
Indiana	427,500	113,062	101,737	111,392	53,600	30,390	17,320
Missouri	398,063	127,338	117,467	68,453	52,050	22,325	10,430
Illinois	368,033	111,592	106,211	61,051	41,740	19,171	28,269
Kentucky	363,548	98,539	90,715	76,189	54,308	18,874	24,924
West Virginia	306,088	71,492	92,027	58,740	40,756	21,305	21,769
Virginia	301,859	62,459	84,257	43,205	25,101	51,009	35,828
Pennsylvania	251,310	59,690	71,349	45,508	31,511	21,880	21,372
Tennessee	244,059	69,949	69,431	54,150	21,012	19,161	10,357
Iowa	223,198	57,822	62,394	36,931	29,077	27,230	9,745
Kansas	170,256	52,427	40,291	30,144	23,267	9,463	14,665
Michigan	160,997	41,073	39,127	27,372	24,518	14,321	14,586
18 other states	570,843	158,613	126,882	120,821	69,986	48,505	46,035
Total all states	4,296,573	1,167,755	1,157,184	816,799	532,668	347,492	274,675

sawtimber volume estimates. To be included in sawtimber volume estimates, a minimum of one 12-ft, or two non-contiguous 8-ft, sawlogs is required. In western portions of the black walnut range, trees often do not reach sufficient height to contain the minimum sawlog requirement. However, industry will use smaller length logs if they meet other quality and size standards. For example, in Nebraska short-log black walnut trees represent an additional 7% of the total black walnut sawtimber volume in the state. Many of these trees are of the highest quality and are marketed worldwide.

Each of the top 12 states had more than 160 million board feet of black walnut sawtimber. Ohio had the most sawtimber volume with more than 500 million board feet. In total, the top 12 states accounted for 87% of the black walnut sawtimber volume in the United States as of the most recent inventories. While the top 12 states were the same states for both growing-stock and sawtimber volume, they differed in order of total volume. Indiana, which was fourth in growing-stock volume, was second only to Ohio in total sawtimber volume. Kentucky, second in growing-stock volume fell to fifth in sawtimber volume. Kentucky's lower sawtimber to growing-stock volume ratio indicates a stronger demand/market for black walnut in Kentucky compared to other states. This has caused more of the larger sawtimber-sized trees to be harvested, resulting in smaller, more recently established, trees.

Considering only large trees (>21 in. d.b.h.), Virginia had the most volume followed by Illinois, Kentucky, West Virginia, and Pennsylvania. All five of these states had at least 20 million board feet of sawtimber in the largest diameter class. In Virginia, 29% of the total black walnut sawtimber volume in the state was in trees at least 19 in. d.b.h., compared to a national average of 14%. Virginia alone accounts for 14% of the black walnut sawtimber volume larger than 19 in. d.b.h. in the Nation. As one compares the sawtimber volumes for smaller diameter classes, other states begin to dominate but Virginia is the current king of large diameter black walnut sawtimber.

GROWING-STOCK GROWTH, MORTALITY, AND REMOVALS

Black walnut growing stock averaged 55.2 million cubic feet of gross growth and 11.5 million cubic feet of mortality each year across the country in the most recent inventories (Table 7). The result was an average net annual growth rate of 43.6 million cubic feet, 2.7% of the Nation's total growing-stock volume. This net annual growth would provide enough wood to

Table 7.—Black walnut growing-stock volume and average annual gross growth, mortality, net growth, and removals

State	Growing stock					
	Volume	Gross growth	Mortality	Net growth	Removals	Net gain or loss
	Thousand cubic feet					
Ohio	183,618	5,751	1,049	4,702	2,635	2,067
Kentucky	183,349	5,521	1,454	4,067	2,279	1,788
Missouri	147,480	4,120	1,789	2,331	2,103	228
Indiana	127,223	5,309	1,335	3,974	1,978	1,996
West Virginia	123,743	4,063	604	3,459	1,086	2,373
Illinois	119,080	5,335	1,186	4,149	875	3,274
Virginia	115,219	2,723	636	2,087	2,746	-659
Pennsylvania	100,498	4,068	359	3,709	449	3,260
Tennessee	91,251	3,556	1,312	2,244	865	1,379
Iowa	63,757	2,372	159	2,213	699	1,514
Kansas	58,370	2,480	305	2,175	485	1,690
Michigan	54,447	1,939	181	1,758	474	1,284
18 other states	220,107	8,895	1,070	7,825	2,699	5,126
Total	1,588,142	55,182	11,534	43,648	19,373	24,275

make a desk completely out of black walnut for every one of the estimated 945,000 occupied households in Kansas or to make a stack of black walnut wood that was 4 ft high and 4 ft wide that would almost stretch from Springfield, Missouri to Richmond, Virginia.

States with above average net annual growth rates when compared to total growing-stock volume include Kansas, Pennsylvania, Illinois, Iowa, Michigan, and Indiana. Kansas and Pennsylvania led all states, each averaging annual net growth rates that were 3.7% of their total growing-stock volume. Missouri and Virginia show the lowest percent of growing-stock growth to total volume ratio in the United States, both having a net growth rate of less than 2%. Missouri's lower net growth rate was in-part due to higher than average mortality rates.

Average annual mortality was estimated to be 0.7% of the Nation's total black walnut growing-stock volume. The cause of death for the vast majority of black walnut mortality was unknown (> 80%). Of the known causes of black walnut mortality as identified by FIA field crews, weather related factors and diseases were most commonly reported.

Tennessee and Missouri had the highest average annual mortality rates, both being about 1.2% of total volume. States with low mortality rates included Iowa, Michigan, Pennsylvania, West Virginia, and Kansas. Iowa's black walnut average annual mortality rate was a mere 0.2% of its total growing-stock volume.

Growing-stock average annual removals averaged 19 million cubic feet per year. Growing-stock removals include all removals for timber products, changes in land-use to where the land is no longer classified as timberland (clearings, development, etc.), and trees that are cut but not utilized. This removal rate represents 1.2% of the total growing-stock volume in the Nation. Most states had statistically similar growing-stock removal rates, although Virginia reported a removal rate (2.4% of its total growing-stock volume) that was double the national average. Even though Virginia has only 63% of the growing-stock volume of Ohio, it has a higher removal rate. The high removal rates in Virginia probably could be attributed to harvesting and urban/suburban sprawl pressures.

If mortality and removals are subtracted from total gross growth, the net result is an increase of 24 million cubic feet of black walnut wood each year in the United States. This compares to the average annual increase of 22 million cubic feet of black walnut that was calculated based on comparing 1962 total growing stock with 1989 total growing stock (see discussion in volume section). Thus, the average annual increase in growing stock is probably between 22 and 24 million cubic feet. Comparing average net growing-stock growth to removals shows a ratio of 2.25/1.0 which reflects a growing resource that has the potential to greatly increase the current removal rate while still achieving long-term sustainability.

With the high economic values associated with black walnut, one could raise the question as to why the market place is not increasing the removal rate to more closely approximate the growth rate. Factors to consider include that: much of this growth is occurring on smaller trees that have not attained a size appropriate for utilization, growth occurs on many poor quality trees that have limited utilization potential, and growth is occurring on sites that are inappropriate or currently unavailable for harvesting.

The national average net annual gain in volume of black walnut of between 22 and 24 million cubic feet represents about 1.5% of the Nation's total black walnut growing-stock volume. The net annual increase in growing-stock volume as a percentage of the state's total growing-stock volume was largest in Pennsylvania, Kansas, and Illinois. Each of these states have a net annual increase of at least 2.5% of their total growing-stock volume. Missouri, with a net annual gain of 228 thousand cubic feet or 0.1%, is nearly static in terms of annual changes in total growing-stock volume. This is primarily due to above average mortality and removal rates. The current condition in Virginia is different than in any other state in the entire range of black walnut, primarily due to its large volume of sawtimber-sized trees. Virginia is experiencing an annual decrease of 659 thousand cubic feet. If the current conditions continue into the future in Virginia, the black walnut resource will dwindle, which will have adverse economic impacts on industry.

SAWTIMBER QUALITY

Black walnut sawtimber removals have a direct relationship to the quality of the trees available. Therefore, discussions concerning resource quality must precede discussions of the utilization of the resource. Because FIA field crews do not grade every tree on a field plot, only percentages are used to display quality aspects of the black walnut resource. Both the diameter and length of each potential log in each tree are important considerations in the tree grade formulas. The minimum small end d.i.b. (diameter inside bark) for grade 1 is 13 in. and 11 in. for grade 2 (Hanks 1976). Both of these minimum diameters are well below what the industry would consider necessary for "high quality."

In 1965, approximately 45% of the volume in walnut sawtimber in Illinois, Kentucky, and Missouri was in grades 1 and 2 (Quigley and Lindmark 1965). We are assuming that these regional estimates are representative of the entire black walnut resource at that time. As a comparison, 38% of the black walnut sawtimber in the most recent inventories were grade 1 or 2 (Table 8).

Many field foresters, log-buyers, and industry officials feel that the decrease in quality resulted from a decrease in not only quality but also in the size of the timber available for harvest. However, a comparison of sawtimber volume by diameter classes between 1962 and 1989 show that, in fact, the average diameter of sawtimber trees in the United States has been increasing. The percent of black walnut sawtimber in the largest diameter classes, above 19 in. d.b.h., actually increased from 10% in 1962 to 14% in 1989.

Table 8.—Percent of black walnut sawtimber by grade

State	Grade			
	1	2	3	4
	- - - *Percent* - - -			
Ohio	9	22	63	7
Indiana	11	30	50	9
Missouri	5	19	45	31
Illinois	13	38	41	8
Kentucky	12	34	50	4
West Virginia	13	31	38	18
Virginia	4	30	55	11
Pennsylvania	3	25	46	26
Tennessee	5	18	63	14
Iowa	12	34	50	4
Kansas	24	37	39	0
Michigan	20	46	31	3
18 other states	10	27	53	10
Average	10	28	51	11

Kansas has the largest percentage of the best quality trees compared to the total sawtimber volume in each state. Almost one-fourth of all of the graded sawtimber-sized black walnut trees in Kansas were classified as grade 1. By comparison, in Missouri only 1 out of every 20 sawtimber-sized black walnut trees was classified as grade 1. Grade 1 generally indicates trees that have the potential to be utilized as veneer.

More than half of the black walnut sawtimber in the United States was graded as grade 3 in the most recent inventories. This grade is suitable for lumber and other miscellaneous products and can often have more "character" than higher grades. For example, furniture made from low grade black walnut lumber with knots and other sound defects adds to the charm and diversity of each piece (Chenoweth 1995).

Black walnut products come from a wide variety of sources beyond the typical forestlands. Because of the economic value associated with black walnut, the eastern United States are scoured for trees that are of the size and condition used in the timber industry. Aside from black walnut, there are not many tree species where limbwood, dead trees, cull trees, and nonforest trees are considered of economic value. We investigated sources of harvested black walnut within the North Central Region. The findings within this region would probably be similar to other regions but, if specific data for states outside of this region are needed, we suggest that the respective USDA Forest Service Experiment Station be contacted.

CURRENT ANNUAL REMOVALS

In the North Central Region, an estimated 7 million cubic feet of black walnut growing-stock and 5.3 million cubic feet of black walnut nongrowing stock are currently harvested based on the most recent Timber Product Output surveys (Table 9). Of the harvested black walnut, about 82% (10.1 million cubic feet) was removed from

Table 9. Black walnut growing stock and non-growing stock annual harvest by state and product in the North Central region.

State and product	Growing stock			Non-growing stock						Total		
	Poletimber/ Sawtimber	Logging residue	Total	Limbwood	Cull trees	Dead trees	Nonforest trees	Logging slash	Total	Used	Not used	Harvested
Iowa (1988)	(Thousand cubic feet)					(Thousand cubic feet)					(Thousand cubic feet)	
Sawlogs	463.6	68.9	532.6	-	478.4	-	175.6	225.7	879.8	1,117.7	294.6	1,412.3
Veneer logs	154.4	12.1	166.4	-	0.0	-	22.6	1.1	23.7	177.0	13.2	190.2
Iowa Total	618.0	81.0	699.0	-	478.4	-	198.3	226.8	903.5	1,294.7	307.8	1,602.5
Illinois (1983)												
Sawlogs	674.3	64.4	738.7	14.8	21.6	-	97.1	95.0	228.5	807.8	159.3	967.1
Veneer logs	126.1	9.8	135.9	-	-	-	18.5	9.5	28.0	144.5	19.4	163.9
Illinois Total	800.4	74.2	874.6	14.8	21.6	-	115.5	104.5	256.5	952.3	178.7	1,131.1
Indiana (1990)												
Sawlogs	1,503.0	143.5	1,646.5	32.9	48.2	-	216.4	211.7	509.2	1,800.5	355.2	2,155.7
Veneer logs	307.2	24.0	331.2	-	-	-	45.0	23.2	68.2	352.2	47.2	399.5
Indiana Total	1,810.2	167.5	1,977.7	32.9	48.2	-	261.4	234.9	577.5	2,152.7	402.4	2,555.1
Kansas (1993)												
Sawlogs	370.3	35.3	405.6	8.1	11.9	-	53.3	2.3	75.6	443.6	37.7	481.3
Veneer logs	74.0	5.8	79.8	-	-	-	10.8	0.5	11.4	84.8	6.3	91.2
Kansas Total	444.3	41.1	485.4	8.1	11.9	-	64.2	2.9	87.0	528.4	44.0	572.4
Michigan (1992)												
Sawlogs	372.4	45.5	417.8	8.0	6.4	-	-	68.9	83.4	386.8	114.4	501.2
Veneer logs	47.4	8.9	56.3	0.1	5.1	-	-	13.4	18.7	52.7	22.3	75.0
Michigan Total	419.8	54.3	474.1	8.1	11.6	-	-	82.3	102.1	439.5	136.7	576.2
Minnesota (1992)												
Sawlogs	35.8	8.5	44.3	0.2	1.1	-	-	16.4	17.8	37.2	24.9	62.1
Veneer logs	37.3	7.0	44.3	0.1	4.0	-	-	10.6	14.7	41.4	17.5	59.0
Minnesota Total	73.1	15.4	88.6	0.3	5.2	-	-	27.0	32.5	78.7	42.4	121.1
Missouri (1991)												
Charcoal	8.4	-	8.4	1.4	14.7	0.1	1.7	-	18.0	26.3	-	26.4
Misc. products	33.0	3.0	36.0	-	0.0	-	-	-	-	33.0	3.0	36.0
Sawlogs	1,451.8	215.8	1,667.6	-	1,498.1	-	550.0	706.7	2,754.8	3,499.9	922.5	4,422.5
Veneer logs	338.4	52.3	390.7	-	316.1	-	111.6	3.2	430.9	766.2	55.5	821.6
Missouri Total	1,831.5	271.1	2,102.7	1.4	1,828.9	0.1	663.3	709.9	3,203.8	4,325.4	981.0	5,306.4
Nebraska (1993)												
Sawlogs	71.9	6.9	78.8	1.6	2.3	-	10.4	0.5	14.7	86.2	7.3	93.5
Veneer logs	9.0	0.7	9.7	-	-	-	1.3	0.1	1.4	10.3	0.8	11.1
Nebraska Total	80.9	7.6	88.5	1.6	2.3	-	11.7	0.5	16.1	96.5	8.1	104.6
Wisconsin (1994)												
Sawlogs	189.0	25.9	215.0	1.6	5.3	24.3	-	98.5	129.7	220.3	124.4	344.6
Veneer logs	36.0	6.7	42.7	0.1	3.9	-	-	10.2	14.2	40.0	16.9	56.9
Wisconsin Total	225.0	32.6	257.7	1.7	9.2	24.3	-	108.7	143.9	260.2	141.3	401.5
Total	6,265.4	744.9	7,048.3	68.9	2,417.4	24.4	1,314.3	1,497.6	5,322.7	10,128.5	2,242.5	12,371.0

the site, generally to a processing facility and 18% (2.2 million cubic feet) was left on the ground as logging residue/slash.

Missouri and Indiana were the leading states in the North Central Region in current annual total black walnut harvested volume. These two states had similar levels of growing-stock removals but different levels of non-growing stock removals. Missouri, in 1993, had more black walnut harvested from non-growing stock sources (2.5 million cubic feet) than from growing-stock (1.8 million cubic feet). Indiana's 1990 black walnut harvest from growing stock (1.8 million cubic feet) was five times the harvesting from non-growing stock (343 thousand cubic feet). States besides Missouri with a large percentage of total black walnut harvest from non-growing stock include Iowa and Wisconsin.

Almost 20% of all of the black walnut harvest in the North Central Region was from cull (non-growing stock) trees. Cull trees are on timberlands but they do not meet the requirements for growing stock. Cull trees include short-log trees, trees with excessive sweep and/or crook, trees with excessive taper to where they do not meet the minimum top diameter, and rotten trees. While FIA classifies these as cull trees, they obviously constitute an important part of the supply of black walnut in the region. Missouri and Iowa both had significant volumes of cull black walnut trees that were harvested for sawlogs. In addition to the cull tree harvest, more than 1.3 million cubic feet of black walnut are harvested annually in the North Central Region from trees that are not on timberlands. These trees occur on pasture land, in narrow wooded strips, in windbreaks, and in other locations.

CONCLUSIONS

Some state inventory results from the 1940's through the 1970's seemed to confirm the concerns expressed about the perceived dwindling supply of black walnut. Other states, however, were showing significant gains in volume. Ohio, the number one black walnut state in terms of growing-stock volume, posted a 22% increase in growing-stock volume from 1968 to 1979. Kentucky dramatically increased its black walnut growing-stock volume from 1963 to 1975. Thus, the changing black walnut picture was different depending where one looked. Overall, national compilations show a significant increase in black walnut volume. Much of this increase occurred in the latter half of the period. Inventories in the 1980's and early 1990's show significant gains in black walnut growing-stock volume in all of the big 12 walnut states. Illinois showed the most impressive gain, rising from 44.9 million cubic feet in 1962 to 119.1 million by 1985. In Indiana, growing stock volume increased from 64.5 million cubic feet in 1967 to 127.2 million in 1986.

Why this sudden increase? We suspect the reason is the convergence of several factors. During this same period, the volume of all hardwoods increased dramatically as hardwood forests matured. However, the rate of increase of black walnut was significantly greater than for all hardwoods. This perhaps may be explained by two factors. First, because black walnut is pest resistant and alleopathic, growth is seldom impeded. Secondly, many black walnut trees were already well established in pasture land that reverted to forest land in the 1970's and 1980's. These trees, with their significant volumes, would have been new additions to the total growing-stock volume. Our experience in the North Central Region concerning conversion of pasture land to forest land supports this position. Unfortunately, there is little hard data to either support or refute these conclusions.

More than half of the existing black walnut timberlands are in sawtimber-sized stands. These stands have limited potential for redirecting management toward improved quality and stocking rate. Additionally, many of these older stands have been subjected to practices such as grazing that limit their long-term productivity. Returns on investments are limited in older stands when compared to similar investments on younger stands. However, more than two-thirds of the black walnut trees in the United States are currently less than 5 in. d.b.h., which is an excellent size to actively manage for long-term production. In this size class, pruning, releasing, thinning, and other management activities have the potential to greatly improve the quality as well as the quantity of black walnut in the stand, especially if they are on highly productive sites.

Although the growing-stock volume of black walnut has grown dramatically, there will probably never be an adequate supply of the highest

quality black walnut. But, the supply of high quality black walnut would be enhanced if establishment and management were focused on sites with high productivity potential. With the majority of black walnut timberlands owned by non-industrial private landowners, the future supply is dependent on land management goals that include timber production. Private landowners own land for many purposes other than timber production. If improving the quantity of black walnut is of high priority, public agencies could target these landowners for increased management, technical assistance, and cost-share programs.

Tree distribution records of state forestry agencies show that more than 3 million black walnut seedlings were distributed throughout the eastern United States in 1994 (Johnson 1995). Iowa, Indiana, Illinois, and Missouri account for more than half of all of the black walnut seedlings distributed. In addition, there are many private nurseries that distribute black walnut seedlings. To date, plantations have not made a significant impact on the supply of black walnut timber. However, if this level of planting continues, if they are adequately managed, and if they are planted on productive sites, plantations have the potential to improve the future timber supply of black walnut.

The overall future for black walnut appears bright, the number of black walnut trees has been consistently increasing, there has been an average annual increase in growing-stock volume of 22 to 24 million cubic feet, and utilization techniques are constantly improving. If this growing resource is adequately managed, questions about the long-term supply of high quality of black walnut will be answered.

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HARDWOOD AGROFORESTRY PRACTICES IN TEMPERATE CLIMATES

H.E. Garrett and W.J. Rietveld[1]

ABSTRACT.—Agroforestry, an integrated land-use management approach for production and farmland conservation, is rapidly emerging as a viable alternative to conventional forestry and agricultural practices. In hardwood regions, in particular, agroforestry offers many opportunities. With forest resource analysts predicting dramatic increases in the demand for hardwoods in the future, landowners are seeking environmentally sound land-use alternatives that are also economically viable. Agroforestry offers many alternatives while advancing our land stewardship needs by 1) converting degraded lands, 2) protecting sensitive lands, and 3) diversifying farm production systems while increasing financial gain.

Agroforestry is an intensive land-management system that optimizes the benefits from biological interactions created when trees and/or shrubs are deliberately combined with crops and/or livestock (Garrett *et al.* 1994). As a field of study, agroforestry possesses many qualities that promote the merging of forestry and agriculture and offers the basis for the development of a new, comprehensive, and integrative land-use strategy. Furthermore, the diversity of products associated with agroforestry can help ease the reliance farmers have on income from conventionally-managed grain crops. An opinion held by many is that, when properly designed and implemented, agroforestry can benefit the ailing farming industry, help our nation meet its projected demands for wood, and, in the process, correct many of the environmental problems that have been created through the improper application of forestry and farming practices.

OPPORTUNITIES FOR HARDWOOD AGROFORESTRY

The demand for wood products in the U.S. is projected to increase dramatically during the next few decades. A harvest of 18 billion cubic feet in 1991 will grow to 25 by the year 2050 (Powell *et al.* 1992). Coupled to this increase in wood demand will be an increase in the number of states affected by timber harvesting restrictions. Already the states of Washington, Oregon, and California, three of the top softwood lumber producing states in the nation, are under heavy restrictions. Moreover, public lands, a major source of raw materials in the past will play less of a role in meeting future demands. Harvesting on federal lands peaked in 1988 at slightly more than 14 billion board feet and has steadily declined since. Federal lands contributed approximately 5 billion board feet in 1995 (American Forest and Paper Association 1995).

With the reduction in allowable harvest on federal lands and restrictions being placed on harvesting due to many reasons in states that have been important timber producers in the past, a unique opportunity is unfolding for agroforestry in the central and eastern hardwood regions. With increased demand will come new markets and improved prices for hardwoods (Wiedenbeck and Araman 1993). Since 59% of all timberland in the U.S. is under non-industrial private ownership, the opportunities have never been greater. In the oak-hickory association alone which stretches from the midwest to the east coast and lends itself well to agroforestry practices, more than 114 million acres exist, most of which is privately owned (Sander *et al.* 1983).

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In addition to forested land that is available for conversion to agroforestry practices, substantial farmland acreage is laying idle within the hardwood region that could be placed under productive agroforestry management. Such conversion would not only provide economic returns to the landowner, but also help the nation meet its future need for wood products. It has been estimated that the nation's 600,000 largest farms produce 94% of all agricultural sales. The remaining 1.5 million farms which total approximately 290 million acres in size, produce 6% (Anderson 1995).

With the projected shortfall in meeting the demand for wood products and the availability of such vast acreages of farmland that are in need of being placed back in production, landowners must be made aware of the potential of agroforestry. Properly designed agroforestry practices yield many benefits including wood products, wildlife habitat, improved income, increased biodiversity in agricultural landscapes, decreased wind and water erosion, and reductions in agriculturally-derived contaminants in riparian zones. Furthermore, through the integration of forestry and agricultural technology, the sustainability of a system and rural development can be greatly enhanced.

HARDWOOD AGROFORESTRY PRACTICES

Agroforestry within temperate climates emphasizes integration of trees with crops in such a way as to maximize both conservation and production benefits. While varied in nature, agroforestry can functionally be grouped into one of five distinct practices: 1) Windbreaks, 2) Riparian Buffer Strips, 3) Silvopasturing, 4) Alley cropping, and 5) Forest Farming.

WINDBREAKS

Windbreaks are the oldest form of agroforestry in the U.S. Windbreak practices are of noted importance in the northern Great Plains states (Kansas, Nebraska, the Dakotas, etc.) and western states where they are used for stabilizing microenvironments. Beneficial effects leading to increased crop and livestock production are afforded by properly designed windbreaks. Increases are attributed to reduced wind erosion, improved microclimates, snow retention, reduced crop damage by high winds, and increased crop yields. In general, wind speed is slowed and benefits are derived to a distance of 15 to 20 times the height of trees within a windbreak (Brandle *et al.* 1988).

The design and success of windbreaks has improved dramatically from the early 1930's when single shelterbelts of up to 10 rows were recommended on only one side of an area to be protected. Today's designs advocate narrow windbreaks arranged across an area with spacings within the row and between rows which provide adequate air movement to minimize turbulence and snow piling. Numerous hardwood species such as bur oak, black walnut, black locust, hackberry, cottonwood and others, are commonly used. With a properly designed windbreak, protection is assumed to begin in about year 6 and increase over the next 15 years reaching full protection by age 20. Average yield increases of up to 15% in winter wheat have been observed in Nebraska (Brandle *et al.* 1984).

Furthermore, the benefits of windbreaks to livestock under winter conditions are well documented. Windbreaks are known to reduce animal stress, increase feeding efficiency and improve animal health. One study of livestock on winter pasture in Canada found that unprotected animals required a 20% increase in feed energy, above maintenance, to offset the effects of exposure to a combination of cold temperatures and wind (Webster 1970).

RIPARIAN BUFFER STRIPS

Riparian buffer strips require a mixture of vegetative types (i.e., trees, shrubs and grasses) that are optimally combined on stream- and riverbanks and lake shores to assist in controlling nonpoint sources of pollution while regulating and protecting aquatic habitats. This practice has broad application throughout the U.S. but nowhere is it more important than in states that are heavily agricultural. The riparian buffer strip, perhaps more than any other agroforestry practice, is in need of immediate broadscale adoption because of its multiple conservation and environmental benefits. Properly designed riparian buffers can reduce the adverse effects of traditional farming on stream quality, create suitable habitat for a variety of wildlife species, including aquatic inhabitants, and provide a sustained income from forest and other products. In the hardwood areas of Illinois, Indiana, Iowa,

Missouri and Ohio, more than 85,000 miles of stream- and riverbanks are unprotected by trees and shrubs. An additional 80,000 miles are unprotected or have only minimal protection in the states of Kansas, Nebraska, North Dakota and South Dakota (Garrett *et al.* 1994).

Designs consisting of strips of hardwood trees along the drainage bordered to the outside by strips of shrubs and grasses are becoming more common and have proven to be very effective in filtering out "would be" stream contaminants (Schultz *et al.* 1993). Forested buffer strips 90 to 150 ft in width have proven to be effective in reducing nitrogen in groundwater by 50 to 100% and in surface runoff by 78 to 98% (Lowrance 1992). While complete information on the optimum width and the economic benefits of buffer strips are lacking, estimates of the cost of cropland sediment in reservoirs in the U.S. runs as high as $200 million annually (Crowder 1987)

SILVOPASTURING

Silvopasturing is a tree-livestock practice where forages are grown with trees under intensive grazing management. While it has been researched most extensively with pines in the southern U.S., the practice has great potential with hardwoods. Tree densities in silvopastoral practices vary greatly with tree species and age, site conditions, and light requirements of forage species. Tree (crown) density greatly influences forage yields (Lewis *et al.* 1984) with yields typically decreasing as tree density increases beyond a threshold value. However, with proper management of tree density and forage species selection, increases in forage yields (Garrett and Kurtz 1983, Dawson 1983) and quality (Smith 1942) are possible.

Little information has been published on the economics of silvopastoral management in hardwoods. However, a 5-year study of domestic forages under loblolly pine revealed that two out of five alternatives studied yielded greater internal rates of return than the open-grown, forage alternative (Clason 1994). Similar findings would be expected for many hardwood species and selected forage combinations.

ALLEY CROPPING

Alley cropping is a practice where tree rows are widely spaced creating alleyways for growing companion crops. In this practice, tree rows are spaced to accommodate the biological needs of intercrops. Within-row spacings, however, must be close enough to produce a "training effect" while providing a surplus of trees from which one can select the final crop trees. Closer within-row spacings also provide better protection of the site (e.g., erosion control) early in the rotation period. Within- and between-row spacings will vary with tree species and intercrops planted, management objectives (e.g., an emphasis on wood versus fruit production) and even the availability of farming equipment—alleyway widths may be designed to accommodate headers, disks etc., owned by the farmer.

Studies conducted in Missouri have demonstrated that when black walnut fruit and wood production are both emphasized, a 40- x 10-ft spacing is a good compromise (Garrett *et al.* 1991). Forty feet between rows provides sufficient light to accommodate even many shade intolerant conventional row crops for up to 10 years. Ten feet between trees within the row provides additional trees from which a final 30 plus quality trees per acre can be selected. For landowners interested in growing intolerant, conventional row crops for more than 10 years, spacings of more than 40 ft between rows is recommended. An east-west row orientation is desirable to provide maximum light for intercrop species.

Numerous economic assessments have been conducted on agroforestry alley cropping with typical internal rates of return ranging from 4 to 11% (Kurtz *et al.* 1984). Moreover, tree species which yield especially high-value wood products and fruit or other marketable products have obvious advantages over low-value species which produce only wood products. Assessments made of alley cropping on marginal farmland have shown that it produces land expectation values comparable to those of traditional agricultural systems (Lottes 1985). Gordan and Dawson (1982) demonstrated that the planting of valuable hardwood species with nitrogen-fixing woody and herbaceous types is an economically viable alternative to conventional row crops on these sites. Furthermore, with the growing importance of the oriented strand board (OSB) industry in the U.S., new opportunities exist for growing biomass species (cottonwood, willow, silver maple etc.) using alley cropping technology.

FOREST FARMING

Forest farming consists of creating suitable microenvironments in natural forest stands for growing shade tolerant specialty crops sold for ornamental, culinary, or medicinal uses. In the hardwood region of the eastern U.S., forest farming emerged in the northeastern and Appalachian states but is gaining emphasis in the remainder of the region. Its popularity is rapidly growing throughout the midwest as woodland owners become more aware of the economic aspects of special forest products. Naturally forested areas throughout the hardwood region provide excellent opportunities for the production of specialty crops. Currently, most forest specialty crop production is passive and does not qualify as agroforestry using the strict definition. The potential, however, for increasing the economic gain of these crops through intensive management is rapidly being recognized as markets develop for an increasing number of plants common to the understories of hardwood forests.

Recent surveys conducted in the Pacific northwest on the economic and marketing implications of special forest products have been most revealing (Schlosser *et al.* 1991). In 1989, native plants, growing in the understory of forests and sold as floral greens in the Pacific northwest and coastal British Columbia, created an industry which employed over 10,000 workers and generated an estimated $128.5 million in sales (Schlosser *et al.* 1991). Similarly, the commercial harvest of wild edible mushrooms in the Pacific northwest has grown into a multimillion dollar industry (Molina *et al.* 1993). In the Appalachian states, ginseng has become an important crop. In Kentucky alone, ginseng is a 5 million dollar a year industry (Hill 1991).

TREE SPECIES SELECTION AND CULTURAL TREATMENTS

Properly designed agroforestry practices, regardless of the one chosen, can yield many benefits but their success requires proper selection and active manipulation of the vegetation. While the potential for agroforestry varies by regions, reflecting the diverse landscapes, values, and regional/local economies, the ultimate success of an agroforestry program depends upon the nature of the biological interactions created, the value of the benefits (economic, environmental etc.) produced and, ultimately, the likelihood of adoption by the user.

In agroforestry practices started from planting, selection of the proper tree species is of paramount importance. In addition to being adapted to the site and producing high-value products (i.e., wood, fruit, specialty products etc.), the trees must create suitable microenvironments to accommodate the needs of companion crops while satisfying special needs such as controlling erosion, improving wildlife habitat, or buffering our waterways from excess nutrients and pesticides. While the emphasis on desirable characteristics of hardwood tree species used in agroforestry will vary to some degree with management objectives, there is a consensus that certain characteristics are generally desirable. Desirable characteristics might include the production of multiple high value products (i.e., wood, fruit, specialty products etc.); generation of light shade; deep-rootedness with minimal surface roots; rapidly decomposing foliage; foliage that minimizes acid-generating potential; a lack of allelochemicals; a short growing season; and, good wildlife food and/or habitat production potential. Tree spacing and the most effective design will vary depending on the management practice, light requirements of the species used and even personal preferences of the landowner.

WEED CONTROL

Weed control is critical to the success of any agroforestry practice. Both mechanical and chemical weed control are used under agroforestry management (Garrett *et al.* 1991). However, when mechanical approaches are used, caution is advised to avoid root damage or damage to the lower portion of the stem from contact with the equipment. Weed control around the base of individual stems should be achieved chemically when conventional farm tilling equipment is employed. Complete weed control by mechanical means is advocated only if some form of precision in-the-row tiller is used (e.g., Weed Badger, Litchville, North Dakota 58461). Equipment of this nature is specifically designed to minimize damage to young trees. It may also prove superior to chemical weed control as a result of the increased aeration and moisture penetration benefits derived from soil-surface scarification. Where conventional equipment is used between rows, depth of tilling should be limited to 6 in. or less (Garrett *et al.* 1989).

Because of the ease of application and past success, chemical weed control is more popular than mechanical. Following planting, herbicides can be applied in a circle around each seedling or, where tree rows are used, along both sides of a row of trees. The area of the control zone around trees will vary with landowner and practice employed. However, in all instances it should be sufficient to minimize the competition for water and nutrients between the woody component and the companion crop. Where sites are erodible, consideration should be given to planting on the contour and using shallow-rooted, "living mulches" in association with the trees, or, a commercial grade mulch, specifically designed for the purpose of weed control (Garrett *et al.* 1991).

FERTILIZATION

There is a limited understanding of fertility needs for the various hardwood agroforestry practices used in the U.S. However, since plants grown together under agroforestry management are in direct competition for nutrients and are grown under microenvironmental conditions that may vary from the 'ideal', one may assume that fertility requirements will differ from those prescribed for conventional forestry or agricultural practices. One may also assume that nitrogen, the element needed most by trees, will normally be the most limiting. Due to nitrogen loss from harvesting agronomic or specialty crops and removing prunings or whole trees, N supplements are required in most agroforestry programs to maintain favorable tree growth. Studies conducted in California under alley cropping, agroforestry-type conditions (forage with Carpathian walnuts) have revealed needs of as high as 200 pounds of actual N per acre, if nut production is the goal (Romas 1985). Immediate research is required in the U.S. for developing fertilization prescriptions within the various agroforestry practices employed.

PRUNING RECOMMENDATIONS

Pruning requirements under agroforestry management varies greatly depending upon the short- and long-term objectives of the practice. However, it is a primary goal in most agroforestry practices to maximize the economic gain (in some practices the emphasis is on conservation benefits), thus, artificial pruning is often an important consideration. In silvopasturing, riparian buffer strips, forest farming and alley cropping, artificial pruning is recommended where enhancement of microenvironments is required for supporting companion crops and/or the cost is justified in increasing the value of the wood produced.

In contrast to conventional forest management practices that emphasize the creation of long, clear boles through pruning, under certain agroforestry regimes shorter boles with larger crowns may be favored for the purpose of creating the proper microenvironment for companion crops or increasing yields of nuts, fruit, or specialty products. In the midwest under walnut (*Juglans nigra* L.) alley cropping management, numerous analyses have demonstrated that larger profits can be realized by sacrificing some clear-log length to increase crown area for nut production (Kurtz *et al.* 1984).

Tip pruning (the removal of the growing tip) of lower lateral branches is a practice unique to some agroforestry management programs under conditions where the operation of large farming equipment in close proximity to trees occurs. In alley cropping, as trees develop, lower branches grow into open areas supporting companion crops and can become entangled in farm equipment resulting in damage to the trees. Tip pruning prevents damage and enables the landowner to maintain greater live crown ratios and faster growth early in the life of the trees than would be possible with complete branch removal (Garrett *et al.* 1991).

THINNINGS

Both the timing of thinnings and the number of trees to be removed in agroforestry practices varies greatly with species, site conditions, and management objectives. Under conditions of riparian buffer strips, harvesting of woody and herbaceous plant components is required to maintain vigorous growth while creating new vegetative development for sequestering surplus nutrients and pesticides. Some studies have shown a leakage of contaminants (especially phosphorus) under conditions of little management (Osborne and Kovacic 1993). Furthermore, many grass, conventional agronomic crops, and specialty crop species used in agroforestry practices are only intermediately shade tolerant. Semi-open, tree-crown conditions, maintained through regular thinnings, are a prerequisite to maintaining vigorous growth. Regulated

thinnings under silvopastoral, alley cropping and forest farming management are especially critical to maintain suitable microenvironments for growth of companion crops. Moreover, in all agroforestry practices, the quality and quantity of wood produced has a direct bearing on the expected economic gain. Since it is not normally a goal to grow low-value hardwoods in agroforestry practices, thinnings are critical to the overall success of any program.

THE CHALLENGE

Modern agriculture and forestry face many challenges and there is a growing demand for the knowledge and expertise needed to develop sustainable agricultural and natural resource systems. As part of an ecologically-based land management system, agroforestry can contribute substantially to generating the ecosystem diversity and processes important to long-term sustainability and profitability. Agroforestry can help us meet our nations future wood needs in a sustainable manner. It offers the basis for the development of a comprehensive land-use strategy that emphasizes the desirability of treating value-creating biological systems as holistic management units rather than as a collection of individual components.

Our challenge is to make agroforestry part of a national strategy to: 1) Develop more environmentally and socially sustainable production systems, 2) Reduce the public cost of resource conservation, 3) Avoid the regulation of conservation, and 4) Provide small family farm owners the opportunity to "turn enough of a profit" to preserve a way of life that is rapidly disappearing from our rural landscape.

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BREEDING AND GENETIC ENGINEERING OF ENGLISH WALNUT FOR NUT PRODUCTION

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ABSTRACT.—A classical breeding program for English or Persian walnut (*Juglans regia* L.) was developed to increase nut production and quality. High heritabilities were found for early nut production, lateral bearing, and kernal quality. Currently the English walnut industry depends on a few cultivars with Chandler making up over 80% of the new orchards. Future cultivars will be bred and selected for late season flowering and increased disease and insect resistance. Before new cultivars are released, they will have been evaluated for 22 sets of descriptors over a minimum of 11 years at four locations. Currently most cultivars are vegetatively propagated by grafting scionwood onto seedling rootstocks. Research continues on other propagation methods including rooting of cuttings and tissue culture. With the latter technique, an *Agrobacterium*-mediated gene transfer system is being used to genetically engineer cultivars for increased resistance to codling moth, *Aspergillis flavus*, bacterial blight, and blackline disease. The current activity in genetic improvement suggests that new cultivars designed to alleviate present and future walnut industry problems will be available in the first decade of the next century.

INTRODUCTION

English or Persian walnut (*Juglans regia* L.) is probably native to the lower altitudes of the mountain chains of Central Asia extending from Turkey and Iran through southern portions of former USSR to western China and the eastern Himalayas (McGranahan and Leslie 1990). Millennia of transport in commerce and widespread naturalization from cultivated trees, as well as extensive deforestation in its native habitat, make precise location of the species native range difficult to determine. Walnuts were mentioned in some of the earliest Chinese texts and are referred to in the Song of Solomon from biblical times. Although "Persian" better describes the native range of this walnut species, the most common name for it in the United States is English walnut, apparently because the nuts were shipped from England to the colonies.

Wild walnut stands still exist in parts of Central Asia but these are endangered by deforestation, especially in countries of the former Soviet Union. The burls on the old trees are highly valued by woodworkers and regeneration is scarce due to grazing. As part of genetic improvement it is essential to preserve the germplasm of these native stands.

English walnut is one of about 20 species in the genus *Juglans*. It is characterized by four-chambered nuts which dehisce and separate from the hulls at maturity. The diploid chromosome number is 32 like other *Juglans* species. Trees are monoecious with male flowers borne in catkins and female flowers in pistillate spikes of 2 (-5) flowers at the tips of terminal or lateral shoots. Flowering is dichogamous with either the male (protandry) or female (protogyny) flowers maturing first. Pollen is wind-borne and the dichogamy promotes outcrossing.

The bearing habit is relevant to genetic improvement; laterally bearing genotypes tend to have crops at a younger age (2-5 years from seed) and have higher yields overall. This bearing habit is often associated with smaller tree size as well.

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Most of the germplasm collected from Europe is terminal bearing while some accessions collected from parts of China and central Asia exhibit extreme precocity and pronounced laterally bearing.

Major walnut producing regions of the world are United States with about 236,000 tons, Europe with 202,000 tons and China with 192,000 tons (FAO Yearbook 1993). In the U.S. the major nut production area is California where almost 200,000 acres are planted with *J. regia*, primarily in the Central Valley. Yields per acre can be as high as 4 tons, although a good yield is 2 to 3 tons/acre. The farmgate value is 2.5 to 3.5 million dollars per year. Common cultivars are Franquette, Hartley (most common), Payne, Vina, Chico, Howard, Sunland, Chandler (most common in new plantings), and Tulare (recently released).

Walnut scionwood is commonly grafted on seedling rootstocks of Northern California black (*J. hindsii*) or Paradox hybrid walnut (McGranahan and Catlin 1987), either by budding or whip grafting. Growers can purchase the seedling rootstock and graft it themselves or can purchase grafted trees. The nurseries commonly graft the seedling rootstock at the beginning of second leaf and make the grafted trees available at the end of that growing season. Some nurseries also sell 1-year-old grafted seedlings that were budded in the same year they germinated. In the 1980's micropropagation was touted as a means to commercially produce clonal rootstock and "own-rooted" cultivars, but the one commercial lab that tried found the costs prohibitive (John Driver, Dry Creek Labs, CA, personal communication). Although micropropagation is used commercially in France for selected hybrids between English walnut and Eastern black walnut (*J. nigra*) (Jay-Allemand, Orleans, France personal communication), it is only used in research in California (Leslie and McGranahan 1992). Instead interest has increased recently in propagation by cuttings. Improvement in techniques coupled with clonal selection for rootability make this method of propagation promising (Sutter and McKenna 1995).

Other methods of propagation have been developed for research purposes (Preece *et al.* 1989, Van Sambeek *et al.* 1997). Somatic embryos derived from immature zygotic embryos (Tulecke and McGranahan 1985) or from anther tissue (Mendum and McGranahan 1995) are used as the target tissue for foreign gene insertion via *Agrobacterium tumefaciens* (McGranahan *et al.* 1988, McGranahan *et al.* 1990). Somatic embryos are repetitively embryogenic if maintained in the dark on basal media with weekly transfers. Well-formed embryos can be germinated after dehydration, and transferred to soil or, more commonly, micropropagated and budded onto seedling rootstock. Research is currently underway to develop methods that will allow commercial production of own-rooted cultivars from somatic embryos (John Driver, personal communication). However the trueness-to-type of cultivars propagated through somatic embryogenesis is unknown, and genetic stability may be an insurmountable problem.

GOALS FOR GENETIC IMPROVEMENT

Harold Forde and Gene Serr established a breeding program at the University of California in the late 1940's (McGranahan and Forde 1985). Their goal was to develop cultivars that combined lateral fruitfulness with a late season phenology and high quality kernels. This was challenging because in the germplasm available, late season phenology and high quality kernels were always associated with the terminal bearing habit. In addition, germplasm sources of lateral fruitfulness were scarce. However heritability estimates were high for most traits of interest to breeders (Hansche *et al.* 1972) and a total of 13 cultivars were released before the program terminated in 1978 (Serr and Forde 1968, McGranahan and Leslie 1990, Tulecke and McGranahan 1994). All are laterally fruitful. One of the cultivars, Chandler, currently makes up over 80% of the new plantings (Hasey *et al.* 1994).

For minimum acceptability, a commercial English or Persian walnut cultivar must have nuts with a sound shell, over 48% kernel, light colored kernels, and acceptable flavor. Nut and kernel size varies with age and yield, but 6 g per nut is the minimum kernel weight accepted in a new cultivar. Cultivars that flower after the spring rains have ended, about mid-April in the Central Valley of California, are superior to those that flower earlier because rain is involved in the infection process of walnut blight caused by the bacterium *Xanthomonas campestris* pv *juglandis*. These mid- or later-season cultivars also tend to escape damage from codling moth (*Cydia*

pomonella) and navel orangeworm (*Amyelois transitella*). However, they also have a later harvest date which can be undesirable. The final criterion for minimum acceptability is that new cultivars have lateral fruitfulness and the associated precocity.

New traits that are of high priority in the current cultivar breeding program include:

Short season

Chandler walnut is a high yielding, laterally fruitful cultivar with uniquely high quality kernels and a late harvest date. Chandler has set a new standard for walnut cultivars but is also leading to a possible lack of genetic diversity in future walnut orchards due to excessive planting. Although much of the impact of genetic uniformity is unknown, it has already been recognized by the industry that a glut of walnuts at Chandler's late harvest date will be difficult to process. In addition, the late harvest date precludes efficient processing and marketing before the holidays, a popular time for marketing walnuts. Cultivars that leaf out early tend to harvest early as well, but the early phenology leads to severe blight and codling moth infestation. Thus cultivars that leaf and flower relatively late in the spring but harvest earlier than Chandler are desirable.

Blackline disease

Commercially grown English walnuts are affected by several difficult-to-control diseases that affect either the scion or rootstock. Blackline disease caused by the pollen-borne cherry leafroll virus causes no obvious symptoms in the *J. regia* scion until it has spread from infected flowers down the trunk to the graft union (Mircetich and Rowhani 1984). The species (*J. hindsii*) and hybrid (Paradox) commonly used for rootstock have a hypersensitive response to the virus. The hypersensitive response is a form of disease resistance in which cell death prevents further incursion of the virus into a hypersensitive host. In this case, cell death results in the characteristic blackline girdle at the graft union. Once the tree is girdled by the blackline, it dies rapidly, but before the virus reaches the graft union the infected tree can serve as a reservoir of inoculum for new infections. This disease is a serious problem in central California counties but has not spread rapidly into the hotter valleys north and south of there.

Blight resistance

Blight caused by the bacterium *Xanthomonas campestris* pv. *juglandis* is primarily a problem on trees that flower early in the season. Until recently blight could be controlled with copper sprays but copper-resistant bacteria are becoming prevalent and even numerous sprays are ineffective. Breeding for later leafing and flowering cultivars has been successful in reducing disease incidence in the past but the natural association between late flowering and late harvest has introduced the new problem of an over abundance of late harvesting cultivars as mentioned before. Different forms of resistance to blight (Woeste *et al.* 1992) are being investigated for their potential as germplasm in breeding a blight resistant cultivar.

Insect resistance

The most significant insect pest of walnuts is the codling moth, *Cydia pomonella*. Two or three generations of larvae per year burrow into the nuts and make them unmarketable. An affected orchard can lose up to 30% of its yield. Although several chemical sprays are effective, they also kill the natural predators of mites and aphids and often result in a need for additional chemical treatments. Late season cultivars tend to have a lower infestation of codling moth but no resistant

germplasm has been identified. Genetic engineering may provide a source of genes for resistance in the future.

STRATEGIES, PROGRAMS, AND PROGRESS IN GENETIC IMPROVEMENT

CLASSICAL BREEDING PROGRAMS

In the classical breeding programs at the University of California-Davis, backcross breeding is being used to introduce hypersensitivity to the cherry leafroll virus from the northern California black walnut, *J. hindsii*, into English walnut. The process was started in 1984 with the collection and evaluation of progeny of a Paradox tree pollinated by an English walnut. This first backcross generation segregated 1:1, hypersensitive:tolerant, suggesting that hypersensitivity is controlled by a single dominant gene. The hypersensitive offspring were then pollinated by *J. regia* cv. Chandler and their progeny, the second backcross generation, segregated similarly. We are currently in the process of evaluating individuals in the third backcross generation. Our progress has been accelerated by the identification of a molecular marker linked to hypersensitivity, that allows us to evaluate the response to the virus very efficiently (Woeste 1995). The trait which appears to be most difficult to eliminate is the thick shell of the black walnut parent. Only one of the hypersensitive progeny of the second backcross generation has the thin English-type shell. The estimated date for release of a field-tested hypersensitive walnut is not until the year 2015.

Through classical breeding and selection we have continued the work of Gene Serr and Harold Forde, including the release of two cultivars (Cisco and Tulare) and the pending release of another (UC 76-80), all from crosses made at the end of their program (McGranahan *et al.* 1990, McGranahan *et al.* 1992). These were released to fit specific niches, i.e., Cisco as a pollenizer for Chandler, Tulare as a precocious high-yielding cultivar suitable for close plantings, and UC76-80 as a slightly earlier-harvesting alternative to Chandler.

In the current program we make 20 to 30 crosses per year, 100 pollination bags/cross with a goal of at least 30 seedlings/cross. The design is a combination of a half diallel of the superior cultivars and a factorial to include new sources of germplasm. The new sources of germplasm include introductions from China which are highly precocious and genotypes identified for a unique response to the blight bacteria. Crosses to develop walnut cultivars that have a shorter than average period between flowering and harvest are being made solely based on the season length of the parents; more research on the genetics of season length is needed to optimize the breeding strategy for short season cultivars.

Seedlings from controlled crosses are planted on their own roots in "seedling blocks". Evaluations begin after 3 to 5 years. Individuals are evaluated for at least 2 years before decisions are made to discard or continue evaluations. If an individual is still promising after 3 to 4 years of evaluation, evaluations are continued in the seedling block and it is repropagated to three "selection blocks" located in Chico, Fresno, and Davis. After 4 promising years of evaluation in the selection blocks, the individual is made available to growers for evaluation through their Farm Advisors. The earliest a cultivar could be released after planting from seed is 11 years which would represent 22 sets of evaluation data from four locations.

The following data, based on descriptors (McGranahan *et al.* 1994), are collected for evaluation:

Phenology: Leafing date; First, peak, and last male bloom dates; First, peak, and last female bloom dates; Harvest date based on hullability

Bearing characteristics: Male flower abundance (1 - 9 scale); Female flower abundance (1 - 9 scale); Female flowers per inflorescence (number); Lateral bud fruitfulness (percent current season's lateral buds with flowers); Yield estimate (1 - 9)

Nut characteristics (on 10 - 20 nut sample): Nut shape; Nut diameter (mm, cheek); Nut length (mm); Shell texture (1 - 9; 3 = smooth, 7 = rough); Shell color (1 - 9; 3 = light, 7 = dark); Shell seal (1 - 9; 3 = weak, 7 = strong); Shell strength (1 - 9; 3 = weak, 7 = strong); Shell integrity (1 -9; 3 = incomplete, 7 = complete); Shell thickness (mm); Packing tissue (1 - 9; 3 = thin, 7 = thick); Inshell nut weight (g)

Kernel characteristics (on 10 - 20 nut sample): Kernel weight (g); Percent kernel (%); Kernel fill (1 - 9; 3 = poor, 7 = well); Kernel plumpness (1 - 9; 3 = thin, 7 = plump); Kernel color (percent extra light, light, light amber, amber; based on CDFA walnut color chart - Dried Fruit Association of CA, PO Box 270-A, Santa Clara, CA 95052); Kernel shrivel (percent with tip shrivel, moderate, severe); Kernel blanks (percent with black, shriveled kernels); Kernel veins (percent sound kernels with conspicuous veins); Kernel spots (number with light and dark spots).

GENETIC ENGINEERING PROGRAMS

In the Walnut Improvement Program at UC Davis, transformation and regeneration of transgenic plants is considered a means to increase the gene pool available for breeding. Although we have developed the techniques needed to insert genes into cultivar genotypes (Mendum and McGranahan 1995), the stability of the inserted genes and the trueness-to-type of the cultivar have not been demonstrated.

An *Agrobacterium*-mediated gene transfer system is used to transfer selected genes into walnut (McGranahan *et al.* 1988, McGranahan *et al.* 1990, Dandekar *et al.* 1989). Small (about 5 mm), white, repetitively embryogenic somatic embryos are cultivated for 24 to 48 hours with genetically engineered *A. tumefaciens* carrying the desired genes as well as selectable and scorable marker genes. The *A. tumefaciens* naturally transfers the genes into accessible cells of the embryo, some of which are embryogenic. The embryos then have to be grown on a medium containing an antibiotic (usually cefotaxime) that kills the *Agrobacterium* so that the bacteria do not interfere with the multiplication of the embryos. The selectable marker gene we use codes for kanamycin resistance and therefore the embryos are also grown on a media containing kanamycin. With selection pressure from kanamycin, those embryogenic cells containing the gene for resistance to kanamycin are favored and develop into secondary embryos.

The embryo cultures are allowed to complete several generations of secondary embryogenesis on the kanamycin medium and the survivors, presumed to be transgenic, are tested for the scorable marker gene, gus, in a color reaction in which gus-expressing embryos turn blue in the presence of X-gluc (Jefferson 1987). Once embryo subclones are identified as gus-positive by the X-gluc assay, they are further multiplied through repetitive embryogenesis, and retested at least once so that embryos derived from chimeric embryos can be discarded. Transformation is further confirmed through Southern blotting, an analytical method that detects specific pieces of DNA. At this point a subset of embryos is germinated, micropropagated and grafted for field trials. Another subset undergoes preliminary efficacy testing if appropriate.

The genotype of the embryo clone targeted for transformation should be selected on its susceptibility to *A. tumefaciens* (common in English walnut), and its capacity to produce many and high quality secondary embryos. It should also be amenable to micropropagation and rooting or grafting. As a potential cultivar or advanced breeding material, it should be precocious and exhibit the phenotype of a minimally acceptable release.

These requirements are not easy to meet. Our initial transformations were done on the most prolific somatic embryo clones available. These included a Franquette offspring (Delta Franquette) and a Sunland offspring (Su2). The latter proved to be highly precocious in the field and has been the object of transformations for several years. Although still infectible by *A. tumefaciens*, its quality in culture and ease of grafting have declined due to unknown causes and it has been discarded. In its place we have substituted several clones derived from controlled crosses designed to be precocious, and embryo cultures derived directly from Chandler. Their performance in the field has not yet been evaluated.

Several field trials of transgenic walnuts have been established. The first one, planted in 1990 and removed in 1995, contained the marker genes and a low activity Bt (Dandekar *et al.* 1994). The transformed trees flowered in their second year after outplanting and samples of nuts were collected in their 4th and 5th leaf. The embryonic axes of about half of the nuts expressed the gus gene when exposed to X-gluc, indicating that the introduced gus gene was inherited as a single gene, or probably gene complex with the other introduced genes.

The potentially useful genes under investigation according to Dandekar *et al.* (1995) include:

Gene	Problem	Progress (Walnut Improvement Program)
Bt Series 1	Codling moth	Field trial complete; low efficacy
Bt Series 2; synthetic; Monsanto	Codling moth	High efficacy in embryo test; field trial underway
Bt Series 2; synthetic-truncated; Calgene	Codling moth	High efficacy in embryo test; field trial underway
Bt Series 3; synthetic-targeted; Calgene	Codling moth	High efficacy in embryo test; field trial planned
Cherry leafroll virus coat protein	Blackline disease	Low efficacy in *in vitro* shoot test; field trial underway
Rol abc	Rooting difficulty	Field trial underway
Systemic Acquired Resistance (SAR) 8.2; Calgene	Phytophthora root and crown rot	Low efficacy expected; field trial underway
Chitin-binding - rubber tree	*Aspergillus flavus*	Low efficacy expected; field trial underway
Chitin-binding - nettle	*Aspergillus flavus*	Low efficacy expected; field trial underway
Chitin-binding - barley	*Aspergillus flavus*	Low efficacy expected; field trial underway
Snow drop lectin	*Aspergillus flavus*; nematodes	Transformations underway
Rice Xa21	Blight	Transformations underway

FUTURE CONSIDERATIONS

The current activity in genetic improvement suggests that new cultivars designed to alleviate present and future walnut industry problems will be available in the first decade of the next century. Whether the most significant advances will originate from genetic engineering, breeding, or both, is unknown. The performance and stability of classically bred cultivars is well known, that of genetically engineered cultivars will not be known for at least a couple of decades. In addition, since genetic engineering usually entails inserting a single or few genes, if the gene is designed for insect or disease resistance, there is a strong possibility that the pest or pathogen will be able to overcome that resistance before the natural lifespan of the orchard is complete.

Several options are available to delay the appearance of resistance, including using the engineered plant as a trap plant, but the concepts have not been tested in perennial plants. Other problems that may accompany the release of engineered plants are public acceptance and unexpected allergic reactions but these problems will be encountered with other plants long before transgenic walnuts are made available. In spite of the drawbacks and caveats associated with genetically engineered plants, we consider it definitely worth pursuing.

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BLACK WALNUT: PRODUCTION AND TRADE

Bruce G. Hansen and Cynthia D. West[1]

ABSTRACT.—Black walnut (*Juglans nigra* L.) is a native American hardwood tree that grows in the northeastern one-third of the United States and lower Canada. Over 86% of the walnut growing stock is found in just 12 U.S. states. Black walnut has an established reputation as a fine hardwood species in the manufacture of furniture, cabinetry and millwork products. Although U.S. furniture and cabinetry, preferences currently favor light colored woods and finishes, walnut is still associated with finely crafted furniture and cabinets. The following paper provides information on walnut production and market trends and a description of the current use of walnut in furniture products.

INTRODUCTION

Black walnut (*Juglans nigra* L.) is a native American hardwood tree that grows in the northeastern one-third of the United States and lower Canada. Over 86% of the walnut growing stock is found in just 12 U.S. states (Powell *et al.* 1992). These same states account for about 85% of all walnut sawtimber.

Black walnut has an established reputation as a fine hardwood species in the manufacture of furniture, cabinetry, and millwork products. Although U.S. furniture and cabinetry preferences currently favor light colored woods and finishes, walnut is still associated with finely crafted furniture and cabinets. This wood has been so highly valued in the past that a single tree of truly exceptional quality from Williams County, OH, was sold to a veneer company for $30,000 in 1976 (Chenoweth 1995). The following paper provides information on walnut production and market trends and a description of the current use of walnut in furniture products.

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SAWLOG AND VENEER LOG PRODUCTION

Timber Products Output (TPO) assessments are conducted by the USDA Forest Service in conjunction with State Natural Resource agencies to produce detailed information on forest industry, industrial roundwood production, and associated primary mill residues. The TPO's are conducted at various times among the different states. Thus, some are more recent than others. The most recent, Michigan and Virginia, were conducted in 1992; the oldest, Ohio, was conducted in 1983. In addition, in some states assessments are conducted fairly frequently, in others the time between assessments is quite long.

TPO reports were available for 9 of the top 12 states ranked as to volume of walnut sawtimber (Table 1). These reports were used to construct estimates of sawlog and veneer log production, imports, exports, and apparent consumption within these states. For the other three states—Kansas, Tennessee, and Virginia—estimates of sawlog and veneer log production were obtained from telephone contacts with Ron Hackett, Kansas; Bob Wright, Virginia; and Linda Weaver, Tennessee; state utilization foresters; and other knowledgeable individuals.

In developing an overall estimate of total sawlog and total veneer log production the most recent TPO estimates and data solicited in telephone conversations were combined. Obviously, this approach is not without problems. However, looking solely at a particular point in time can

Table 1.—Top 12 walnut states, by sawtimber volume, 1992

State	Sawtimber volume	
	MMbf	Percent of total
Ohio	465	10.2
Indiana	463	10.1
Illinois	416	9.1
Missouri	397	8.7
Kentucky	364	8.0
Virginia	326	7.1
West Virginia	306	6.7
Kansas	304	6.7
Pennsylvania	251	5.5
Tennessee	244	5.3
Iowa	230	5.0
Michigan	120	2.6
All other	682	14.9
Total	4,568	100.0

Source: Forest Resources of the United States, 1992

give an overstatement or understatement of the more long-term situation. One possible benefit of having data from various points throughout the last decade is that cyclical ups and downs inherent in the wood products business may well have been smoothed to some extent.

In these states, apparent consumption of sawlogs and veneer logs may be estimated along with production. Using this information, overall production of walnut sawlogs within the 12 states was estimated at 64.6 million board feet (Table 2). The combined estimate of the production of walnut veneer logs was 12.8 million board feet (Table 3). Both figures are log measure using the International 1/4-inch rule. Combining these figures yields a total volume of 77.4 million board feet. Since these states account for roughly 85% of the total walnut sawtimber volume, total production may be estimated at roughly 91 million board feet (77.4/0.85). This is within 3% of the 93 million board feet Luppold (1994) estimated was produced in 1992 using similar TPO data, forest inventory growth and removals data, and expert opinion to bring everything to a common point in time.

Table 2.—Estimated walnut sawlog production, selected years

State	Year of estimate	Production	Imports	Exports	Apparent consumption
		Mbf			
Missouri	91	17,394	3,565	4,208	16,751
Indiana	90	10,196	3,558	49	13,705
Kentucky	86	6,937	750	5,231	2,456
Ohio	89	6,900	2,500	200	9,200
Tennessee	89	5,905	466	n.a.	6,371
Iowa	88	3,649	2,747	110	6,286
Illinois	83	2,954	510	424	3,040
West Virginia	87	2,900	100	600	2,400
Pennsylvania	88	2,847	248	152	2,943
Kansas	95	2,553	n.a.	n.a.	2,553
Michigan	92	2,297	0	813	1,484
Virginia	95	117	n.a.	n.a.	117
Total	—	64,649	14,444	11,787	67,306

Source: Selected timber product output reports.
n.a. = not available

Table 3.—Estimated walnut veneer log production

State	Year of estimate	Production	Imports	Exports	Apparent consumption
			Mbf		
Missouri	91	3,688	1,112	89	4,711
Indiana	90	3,472	3,065	1,479	5,058
Kentucky	86	1,553	13	1,551	15
Iowa	88	1,084	2,747	n.a.	3,831
Ohio	89	1,083	401	822	662
Illinois	83	760	n.a.	760	0
Kansas	95	602	0	602	0
Michigan	92	324	228	293	259
Pennsylvania	88	127	0	127	0
West Virginia	87	115	n.a.	0	115
Virginia	95	3	n.a.	n.a.	3
Tennessee	89	0	n.a.	n.a.	0
Total	—	12,811	7,566	5,723	14,654

Source: Selected timber product output reports.
n.a. = not available

Four states—Missouri, Indiana, Kentucky, and Ohio—account for nearly 64% of walnut sawlog production within the top 12. Tennessee and Iowa bring the total close to 80%. Five of the top six walnut sawlog producing states are among the top six veneer log producing states. The exception is the replacement of Illinois for Tennessee. In addition, veneer log production is slightly more concentrated than sawlog production with the top four states accounting for over 76% and the top six over 90%. The proportion of walnut sawlog production to total sawlog production for all species ranged from about 0.3% in Pennsylvania to 5.7% in Iowa. The simple unweighted average for the nine states for which these data were available was 1.8%. The proportion of walnut veneer log production to total veneer log production for all species ranged from 0.4% for Pennsylvania to 49.0% for Missouri. The corresponding simple average was 15.4%.

Indiana, Iowa, and Ohio were significant net importers of walnut sawlogs as well as producers. Net imports of these three states accounted for 26%, 25%, and 42% of the total apparent consumption, respectively. On the other hand, Missouri and Indiana were net importers of veneer logs with net imports representing 21% and 31%, respectively. Iowa also is very likely a net importer. Kentucky is a major net exporter of both walnut sawlogs and veneer logs. Table 4 ranks the states according to sawtimber volume, sawlog production, and veneer log production.

EXPORTS

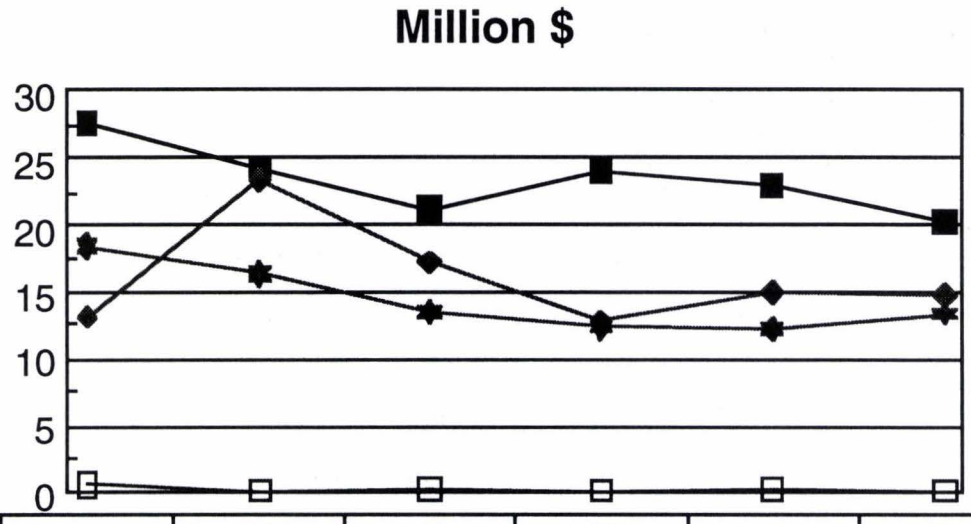
It was only possible to examine U.S. exports of walnut for the period 1990 through 1995 due to serious errors in data reported by the U.S. Department of Commerce during the mid to late 1980's (Luppold 1995). And, although Luppold and Thomas (1991a, 1991b) were able to construct revised estimates for overall exports from ship manifest data, they were unable to get enough detail to accurately assess species performance, especially for walnut.

U.S. exports of walnut logs, lumber, veneer, and plywood totaled $48.5 million in 1995. With the exception of their peak in 1991, the combined value of U.S. exports of walnut logs, lumber, veneer and plywood has averaged between $50 and $60 million during the period 1990 through 1995. In fact, during the last 4 years the value of combined exports has been remarkably stable hovering about the $50 million mark (Fig. 1).

Table 4.—The relative rank of states by sawtimber volume, sawlog production and veneer log production

State	Sawtimber	Sawlog production[1]	Veneer log production[2]
Ohio	1	4	5
Indiana	2	2	2
Illinois	3	7	6
Missouri	4	1	1
Kentucky	5	3	3
Virginia	6	13	12
West Virginia	7	8	10
Kansas	8	10	7
Pennsylvania	9	9	9
Tennessee	10	5	13
Iowa	11	6	4
Michigan	12	11	8

[1] Number 12 is Wisconsin.
[2] Number 11 is Wisconsin.



	90	91	92	93	94	95
logs	27.60	24.30	21.10	24.00	23.10	20.20
lumber	13.20	23.40	17.20	12.70	15.00	14.80
veneer	18.50	16.30	13.50	12.30	12.20	13.40
plywood	0.60	0.05	0.20	0.10	0.20	0.10

*Plywood contains spanish cedar

Figure 1.—U.S. walnut log, lumber, veneer, and plywood exports, 1990 to 1995.

Throughout the period, logs have accounted for the largest share of total walnut exports by value. However, their share has ranged from 38% in 1991 to nearly 49% in 1993 with swings of about 2 to 8% from year to year. Exports of veneer have been relatively consistent throughout the period whereas lumber exports seem to respond in an opposite direction to that of the trade in logs, i.e., when log's share goes up, lumber's share goes down. Exports of walnut plywood have been insignificant accounting for less that 0.5% of the combined value throughout the period.

In 1995, walnut log exports were concentrated with Italy being the recipient of over half of all U.S. walnut log exports (Fig. 2). Five other countries—South Korea, Canada, the United Kingdom, Japan, and Mexico—each accounted for between 5% and 8.5%. In 1990, Italy also had the largest, but much smaller, share at 30%. In contrast, Germany, South Korea, and Japan had much larger shares of the 1990 market than they enjoyed in 1995. Germany's share went from about 20% to less than 3%, South Korea's share went from nearly 16% to less than 9%, and Japan's share went from about 10% to 6.5%. It is important to note from these changes that the export market is not static by any means and success in exporting requires constant knowledge of the market and of the changes taking place.

Since exports of logs to Germany and South Korea declined dramatically, we took a closer look to see if this was a result of data error or possible trend. With the exception of 1993 in the case of South Korea, the declines have been consistent during the period suggesting a trend. Much of the decline in exports to South Korea and Japan may be due to the general reduction in veneer manufacture as Indonesian manufacturers have come to dominate the veneer market in southeast Asia.

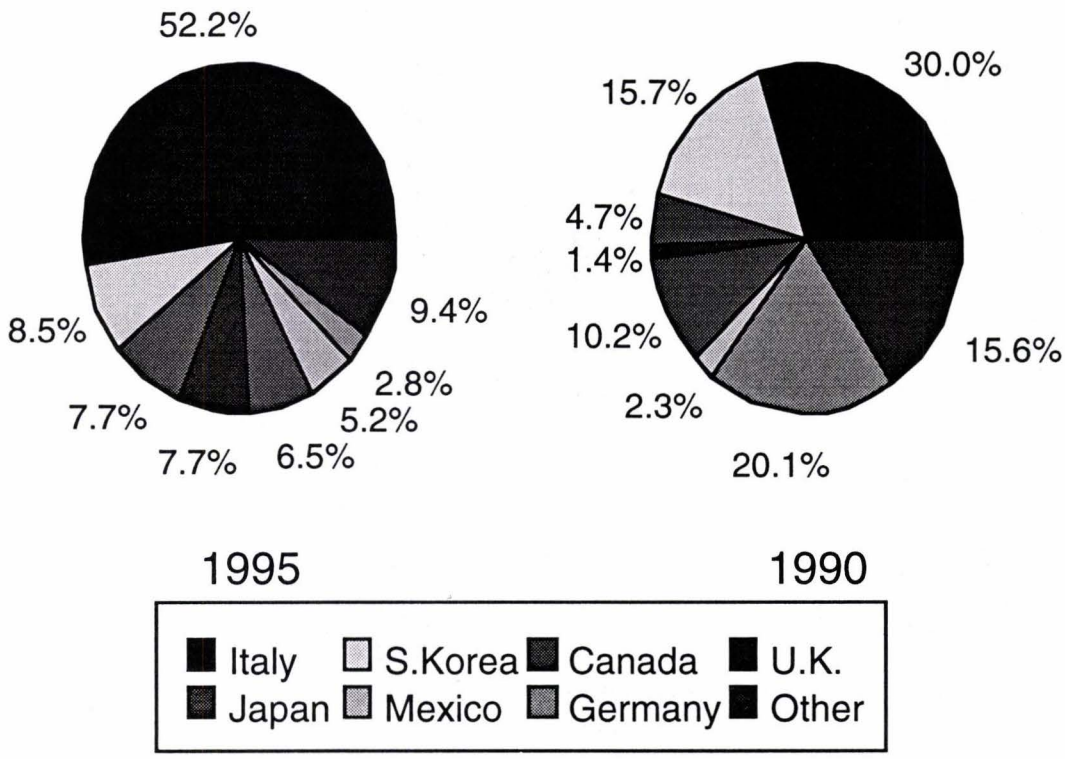


Figure 2.—U.S. walnut log exports by country of destination, 1995 and 1990.

U.S. walnut lumber exports of 21.1 thousand cubic meters (roughly 8.9 million board feet) in 1995 were about equal to their level in 1990. As was the case with logs, the distribution of U.S. lumber exports has changed significantly between 1990 and 1995 (Fig. 3). In 1990, Japan had the largest single share of the market at 21%. In addition, Canada, Italy, and South Korea were large recipients of U.S. walnut lumber exports. Combined these four markets accounted for over 70% of U.S. exports. In contrast, Italy was the top market for U.S. walnut lumber exports in 1995 accounting for 30% of the export total. Canada held the number two spot with 21.5%. Japan's share dropped more than 10 percentage points as did exports to South Korea. On the other hand, Taiwan's share increased from under 3% to 10%. A closer look at both Japanese and South Korean imports of walnut lumber revealed generally similar and consistent declines serving to validate the U.S. Department of Commerce data.

The level of walnut veneer exports has remained more constant during the period 1990 to 1995. However, notable declines in market share for Germany (about 24% to 18%) and Japan (about 9% to 1%) show up in the data. In terms of increases in market share, Egypt, Italy, and Indonesia are particularly noteworthy.

PRICES

Hoover (1995) published delivered log prices in Indiana for four grades of sawlogs and two grades of veneer logs from 1957 to 1994. Figure 4 shows both walnut veneer prices and sawlog prices by grade as reported by Hoover for the period 1975 through 1994. From the graph it can be seen that sawlog prices have been much less erratic than have been veneer logs prices. Not seen on the graph is that, since 1975, real prices (the actual price divided by the producer price index) for all six log categories have been down. However, only the declines in the prices of #2 (-1.3% annually) and #3 (-3% annually) walnut sawlogs have been statistically significant.

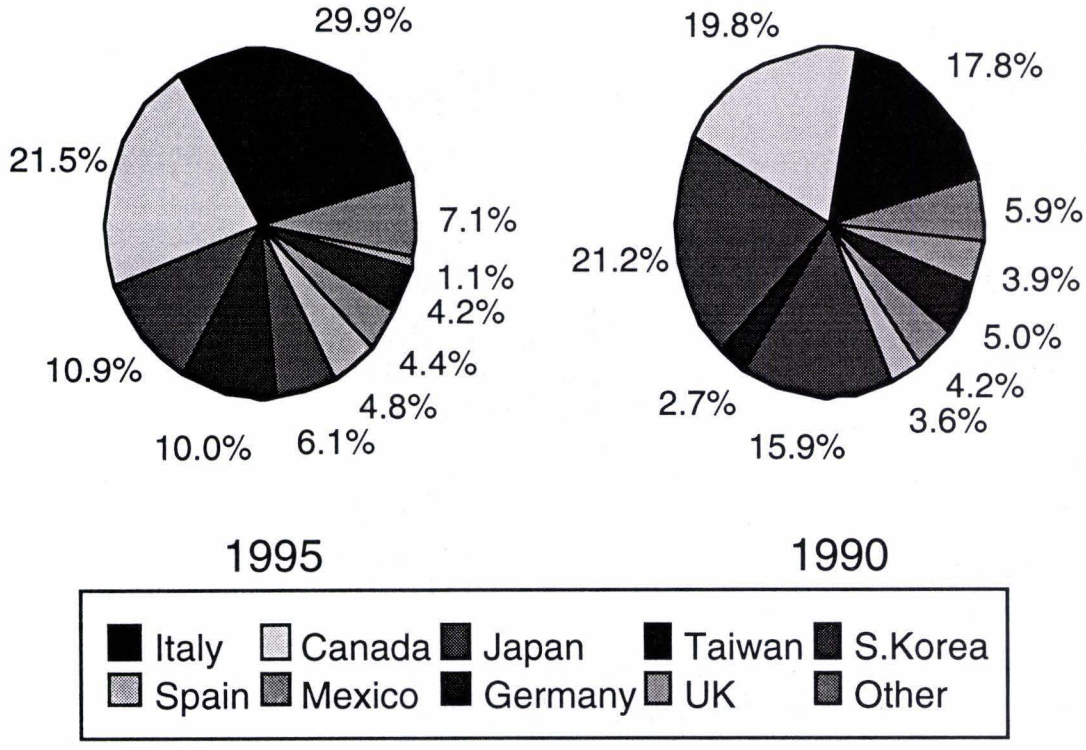


Figure 3.—U.S. walnut lumber exports by country of destination, 1995 and 1990.

Veneer log prices increase with increases in log diameter. However, the most recent survey suggests that sized-based price differences, though still large, may be narrowing (Hoover 1995, Anonymous 1995). Prime veneer log prices in 1995 ranged from a mean of $1,750/Mbf Doyle ($315/cubic meter) for logs 12 to 13 inches in diameter to $4,182/Mbf Doyle ($1,245/cubic meter) for logs greater than 28 in. in diameter. Corresponding prices for select grade were $1,080/Mbf Doyle ($194/cubic meter) to $2,300/ Mbf Doyle ($685/cubic meter).

Rink (1985) reported prices for 1970 of $250/ cubic meter ($1,130 Mbf Doyle) for the average walnut veneer log and $453/cubic meter ($2,050 Mbf Doyle) for those of export quality. By 1980 the price of an export quality veneer log had risen to $1,241/cubic meter ($5,600 Mbf Doyle). There was no price given for the average walnut veneer log in 1980.

Log prices on the export market today seem to be in line with those of the past. For instance, prices for U.S. walnut log exports went from an average of $450/cubic meter ($2,030 Mbf Doyle) in 1990 to an average of $589/cubic meter ($2,650 Mbf Doyle) in 1995 (Fig. 5). These prices are very close to those reported by Hoover (1995) in Indiana for select veneer grade, 16 to 17 inch in diameter, delivered to the mill. Individual country high prices went from $1,048/cubic meter ($4,735 Mbf Doyle) in 1990 to $2,217/ cubic meter ($10,000Mbf Doyle) in 1995, with some individual logs likely selling for even more. These high price markets are generally very thin and usually represent special purpose, custom products that take advantage of unique, often one-time, opportunities. While the average price to all countries in 1995 represents the peak for the period 1990 to 1995, the individual country high in 1995 of $2,217/cubic meter was exceeded in both 1991 ($3,682/cubic meter; $16,570 Mbf Doyle) and 1993 ($4,120/cubic meter; $18,620 Mbf Doyle).

Prices for walnut lumber are reported in the Hardwood Market Report for steamed 4/4 Appalachian lumber only. Interestingly, while the actual price of walnut lumber has increased for each grade since 1975, in real terms walnut prices have fallen. For example, while the actual

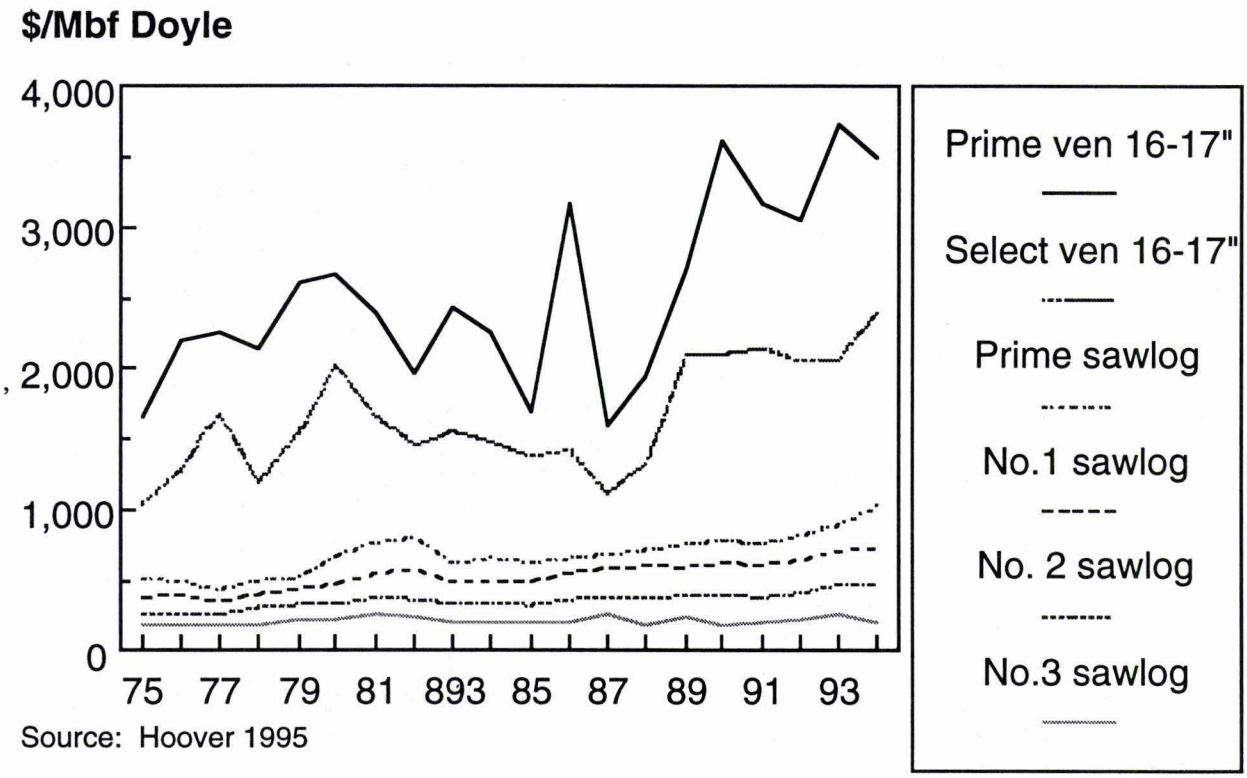


Figure 4.—Actual prices of walnut veneer logs and sawlogs, delivered to Indiana mills, 1975-1994.

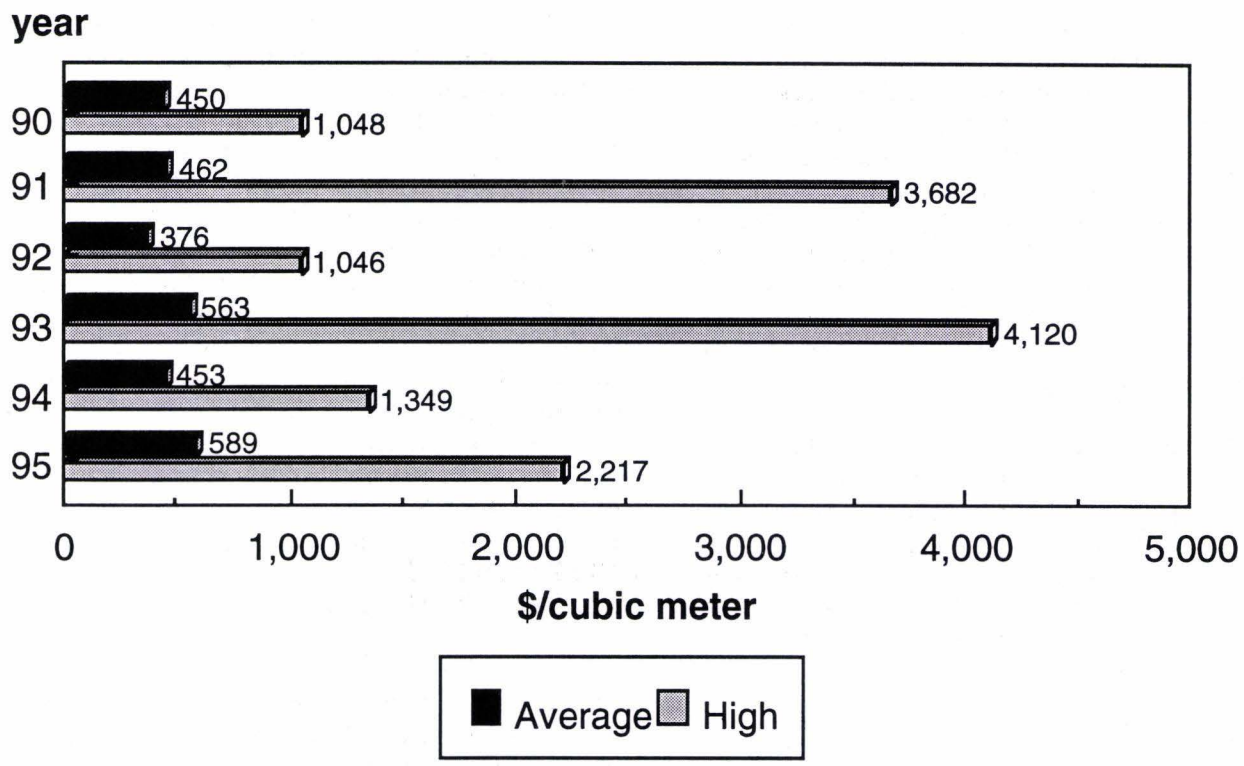


Figure 5.—Average price of U.S. walnut log exports to all countries and the highest individual country price, by year, 1990 to 1995.

price of walnut lumber went from approximately $1,100/ Mbf in 1975 to over $1,600/Mbf in 1995, the real price of FAS walnut lumber expressed in constant 1982 dollars fell from $1,870/Mbf in 1975 to $1,296/Mbf in 1995 (Fig. 6). The real price of #1C during the same period fell from $1,130/Mbf to $686/ Mbf. Prices, in real dollars, for First 1 Face and #2C fell in similar fashion (Fig. 7). In comparison, while the real price of walnut lumber, regardless of grade, has been falling since 1975, the real price of red oak lumber has been rising (Fig. 8).

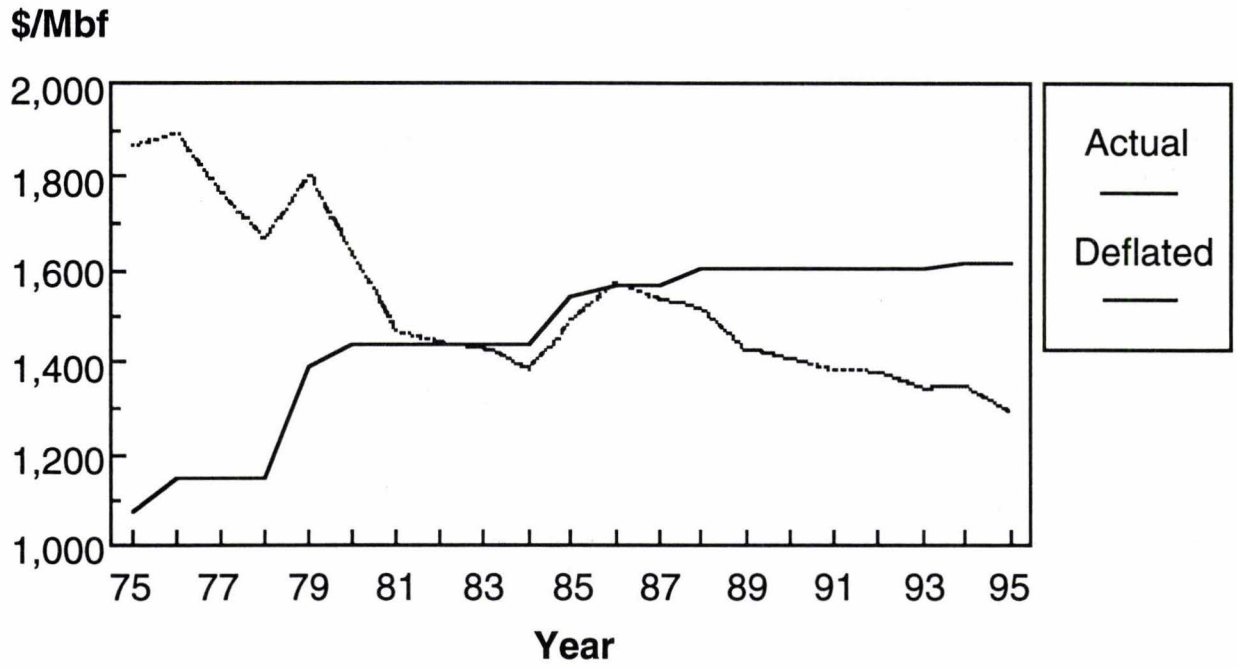
In the more recent period 1990 to 1995, the actual price of FAS and #1C walnut have been relatively constant at approximately $1,600/Mbf and $850/Mbf, respectively. However, in contrast, the actual price (free alongside ship) of lumber exported overseas has risen from about $1,390/Mbf to over $1,660/Mbf (Fig. 9). This, in large measure, reflects the increasing strength of foreign currencies vis-a-vis the U.S. dollar and the willingness and ability of foreigners to pay more to secure a better mix of grades.

Actual prices of U.S. walnut lumber exports went from an average to all countries of $589/cubic meter ($1,020/Mbf) in 1990 to $703/cubic meter ($1,660/Mbf) in 1995 (Fig. 10). The individual country highs for 1990 and 1995 were $743/cubic meter ($1,750/Mbf) and $1,296/cubic meter ($3,060/Mbf) respectively. The individual country high of $1,296/cubic meter in 1995 was down from the highs of the previous 3 years.

Walnut veneer export prices have been very stable ranging from $1.92/square meter ($0.18/square foot) in 1990 and 1994 to $2.18/square meter ($0.20/square foot) in 1993 (Fig. 11). Individual country highs went from $2.71/square meter ($0.25/square foot) in 1990 to $14.54/square meter ($1.35/square foot) in 1995, the high for the period.

ESTIMATING THE SIZE OF THE EXPORT MARKET

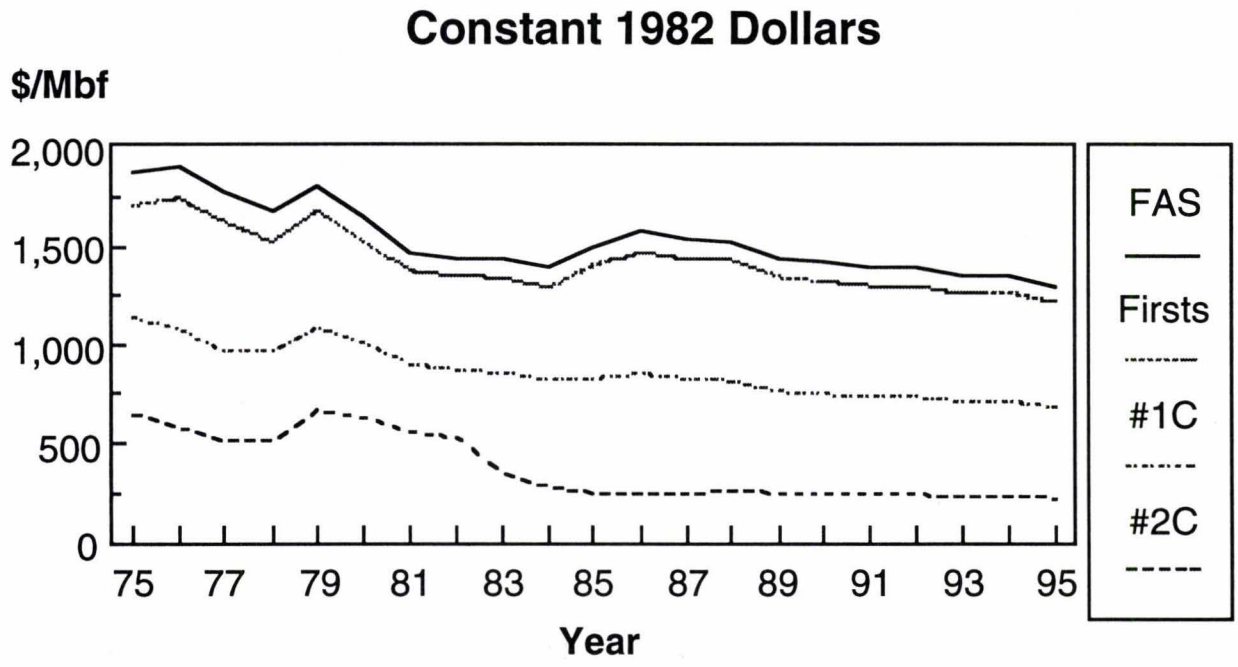
An attempt was made to match U.S. walnut log and lumber exports to U.S. sawlog and veneer log



Prices for the first week in April in each year

Source: Hardwood Market Report

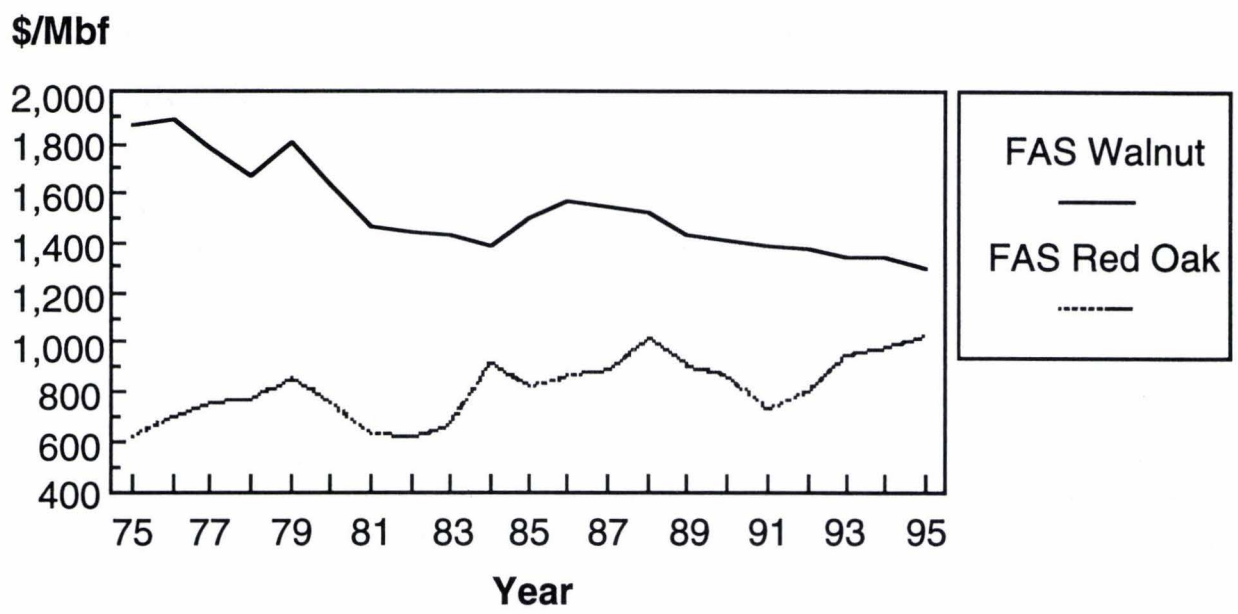
Figure 6.—Actual and deflated (real) price of FAS walnut lumber, 1975 to 1995.



Prices are for the first week in April of each year

Source: Hardwood Market Report

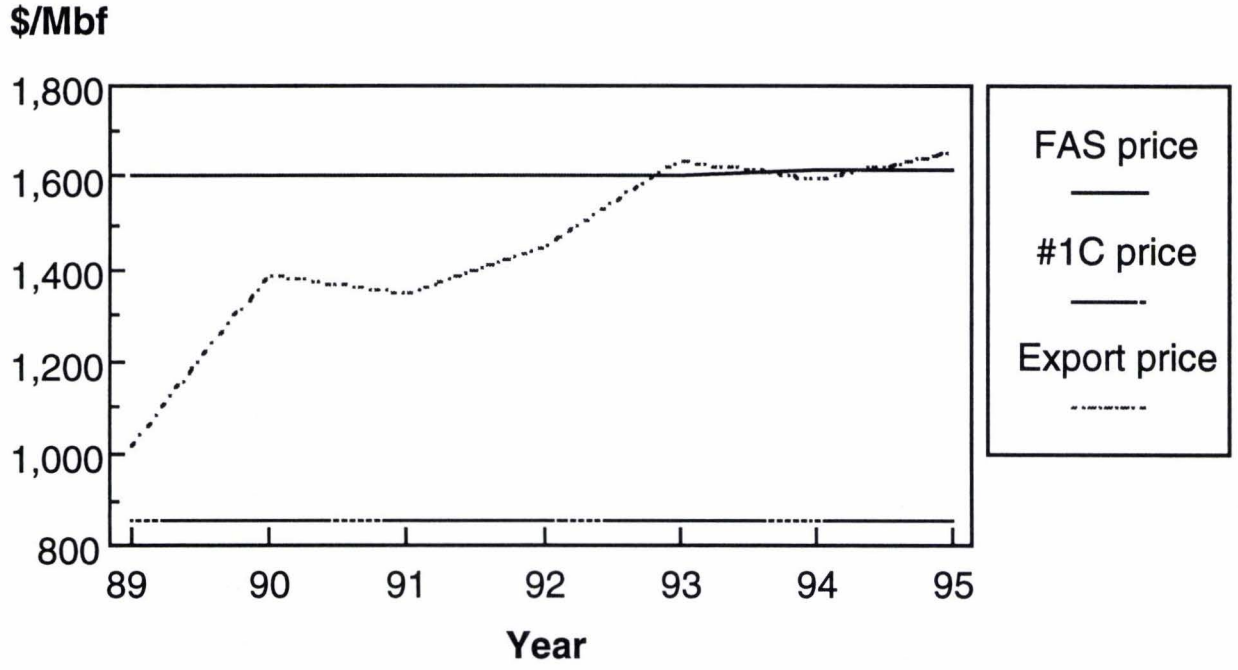
Figure 7.—Real price of FAS, #1-common and #2-common walnut lumber, 1975 to 1995.



Prices are for the first week of April in each year

Source: Hardwood Market Report

Figure 8.—Real prices of FAS walnut and FAS red oak lumber, 1975 to 1995.



FAS and 1C price for April of each year. Export yearly average

Source: Hardwood Market Report/U.S. Dept . Commerce

Figure 9.—Comparison of actual FAS and #1 common walnut lumber prices with the average price (f.a.s.) of U.S. walnut lumber exports, 1975 to 1995.

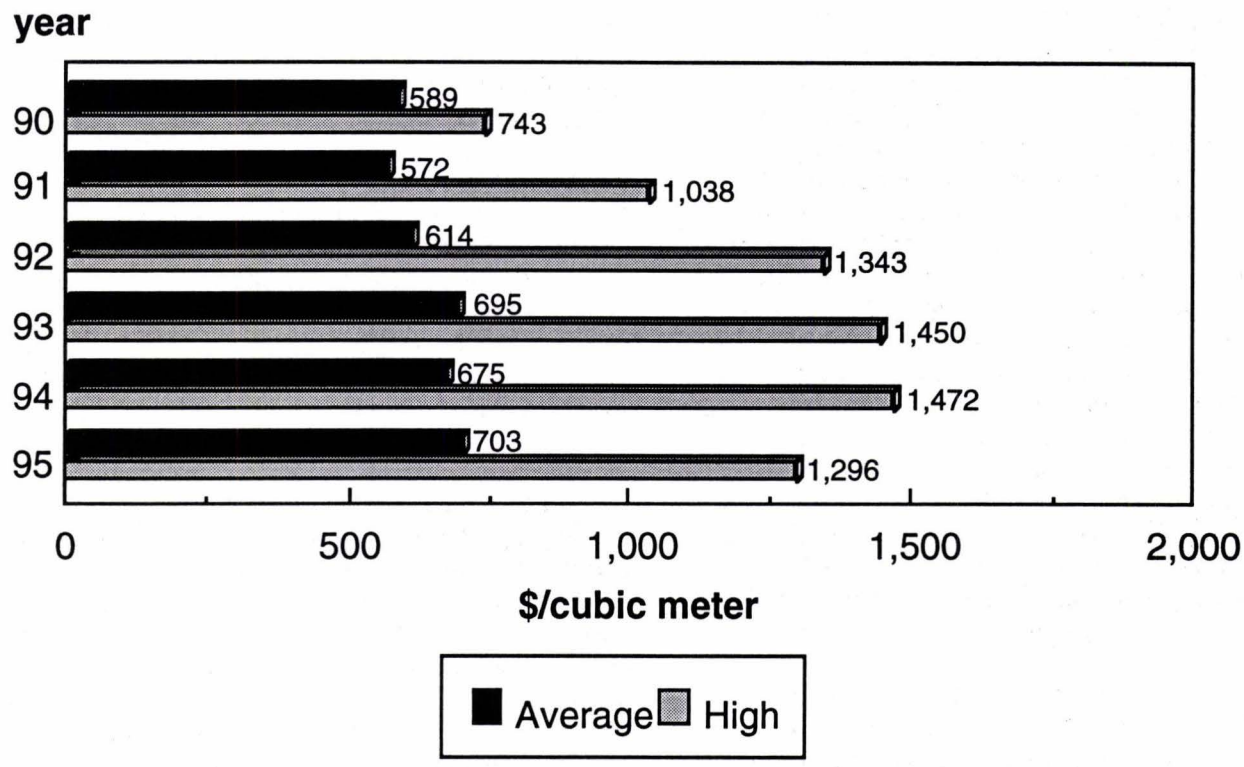


Figure 10.—Average price of U.S. walnut lumber exports to all countries and the highest individual country price, by year, 1990 to 1995.

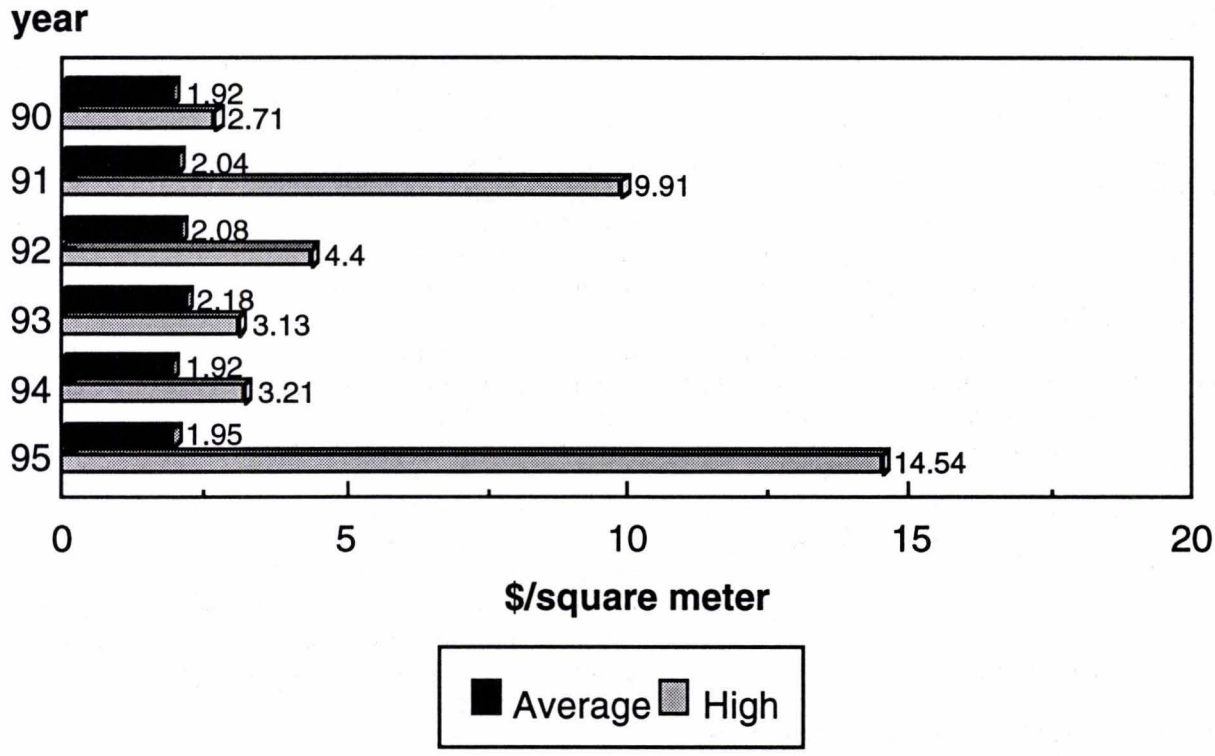


Figure 11.—Average price of U.S. walnut veneer exports to all countries and the highest individual country price, by year, 1990 to 1995.

production to estimate the impact of these two markets on domestic production. To accomplish this comparison requires conversion of volumes to like measure. TPO sawlog and veneer log production estimates are given in board feet based on the International 1/4-inch rule. We converted the TPO estimates in board feet to cubic meters. The exact relationship between board feet in International 1/4-inch to cubic meters depends on log diameter. Conversions factors range from 3.75 cubic meters/Mbf for a 12-inch diameter log to 3.35 cubic meters/Mbf for a 24-inch diameter log. Assuming an average log diameter of between 15- and 17-inches in diameter, the conversion from International 1/4-inch to cubic meters is 3.48 cubic meters/Mbf. Using the 3.48 figure, the estimated combined sawlog and veneer log production from TPO reports and telephone interviews of 91.0 million board feet is equivalent to 316,680 cubic meters.

According to Department of Commerce export estimates, in 1990 the U.S. exported a combined total of 83,800 cubic meters of walnut logs and lumber. This was equal to 26.5% of the total estimated sawlog and veneer log production. In 1995, U.S. walnut log and lumber exports totaled 55,400 cubic meters. This was equivalent to 17.5% of the estimated combined sawlog and veneer log production.

Taking the opposite approach, we converted U.S. Department of Commerce estimates, which are given in cubic meters, to board foot equivalents. The U.S. Department of Commerce assumes their are 4.52 cubic meters for every Mbf of logs regardless of species or diameter, and 2.36 cubic meters for every Mbf of lumber. Using these factors to convert export estimates from cubic meters to Mbf resulted in the following percentages for 1990 and 1995 of 25.4% and 18.1%, respectively. These two estimates are remarkably close to those derived earlier. Consequently, whatever approach or whatever period is used, it is apparent that the log and lumber export markets are important and significant factors in the demand for walnut sawlogs and veneer logs in the United States.

PRINCIPAL USES

According to the revised report, "Black Walnut—An American Wood," by George Rink (1985), the principal uses of black walnut in 1985 were for furniture and fixtures; radio, television, and "phonograph" cabinets; sewing machines; gun stocks; novelties; and interior finish paneling. In furniture applications black walnut is used to a significant degree in dining room and bedroom furniture where it is known to stand up well under hard use. Black walnut is also used in the manufacture of bookcases, desks, living room and occasional tables, as well as office furniture. And, it is still used for interiors in restaurants, cafes, hotels and motels, and public buildings where striking effects and contrasts are desired.

The use of black walnut wood has decline in several markets. Its use in radio, television, and phonograph (stereo) cabinets is diminishing as component stereo systems have largely replaced the "stereo" and metal cabinets, some with wood grain and some without, are used predominately for television sets. Once the dominant wood used in the making of gun stocks because of its strength and shock resistance, today other less expensive woods, plastics, and wood laminates are used to reduce cost in lower priced models. Walnut, however, is still prized at the high end of the market. Chenoweth (1995) provides an extensive discussion of walnut used in the manufacture of gun stocks for those wishing to know more.

Chenoweth (1995) also cites a long list of uses for walnut in novelty items. A partial listing includes bowls, trays, candlestick holders, picture frames, clocks, sconces, plates, salad tongs, candy dishes, plaques, cheese boards, music boxes, and even key holders. Although referred to as novelties, these products represent a serious market in terms of revenue generation.

Chenoweth (1995) suggests that fashion and cost are at the current time negatively impacting the use of walnut in the United States but that in Europe and Asia it is still in great demand. He claims that about half of the veneer quality logs harvested in the United States are exported and that about 60% of the walnut veneer produced in the United States is trimmed for export. Peter Louch of FIRA supports Chenoweth as to European interest in walnut suggesting that walnut plays well to a growing worldwide demand for "exotic temperates."

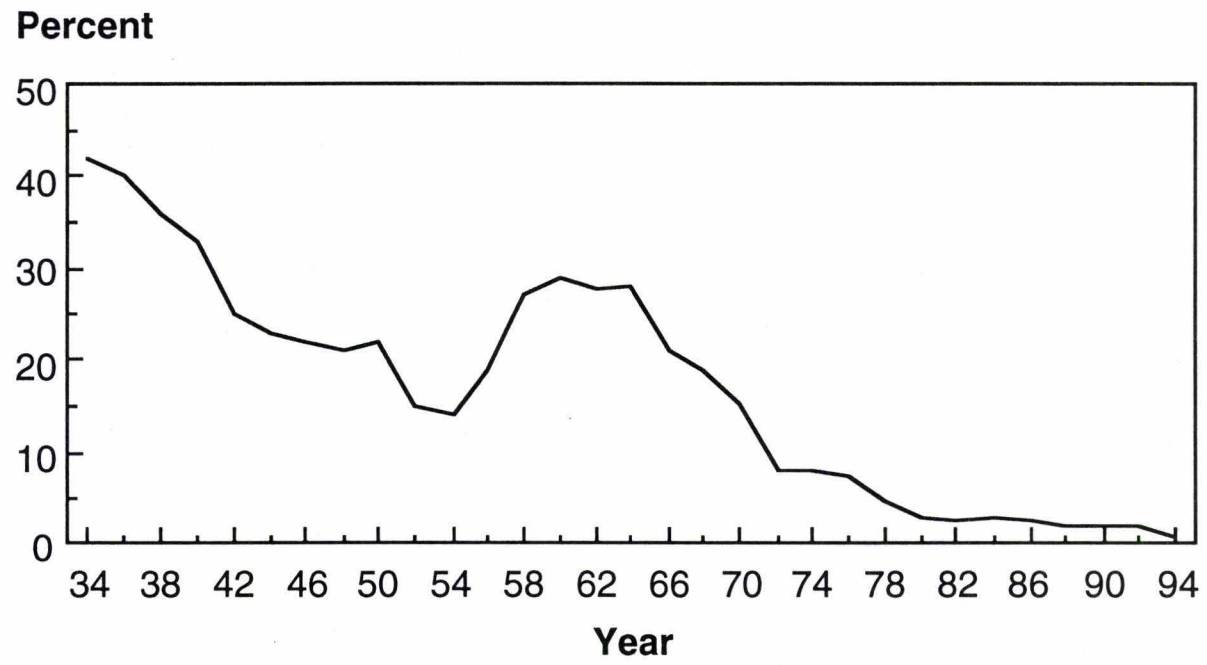
WALNUT USE IN WOOD CABINET AND FURNITURE PRODUCTION

Walnut has always been regarded as a fine American Hardwood used in well crafted furniture and cabinet products. The Fine Hardwood and Veneer Association estimates that walnut was used in almost 30% of wood household furniture 30 years ago (Frye 1996, Fig. 12). Today this organization estimates its use has declined to about 1 to 2% of wood household furniture production.

An independent survey of wood materials use in the furniture industry supports this estimate (Hansen *et al.* 1995). This study, sponsored by Virginia Tech and the USDA Forest Service in 1994, estimated the consumption of walnut lumber by the furniture industry at 7.3 million board feet in 1993 or approximately 0.4% of the industry's total consumption of hardwood lumber (estimated at 1.8 billion board feet). More than half of the respondents to this study who indicated they used walnut, said that walnut accounted for at least 35% of all the lumber they used in their species mix. One third of these companies said that walnut lumber accounted for at least 50% of all the lumber they used. In addition, these companies used a higher lumber grade mix than the industry overall. Respondents using predominately walnut used an average of 78% FAS, 11% No. 1 common, and 11% No. 2 common or below.

Current fashion plays a major role in determining species acceptance by furniture buyers. Lighter colored finishes and woods have been in vogue recently and continue to grow in popularity. Phone conversations with five major furniture producers and lumber manufacturers in the eastern United States revealed that several well known furniture companies have dropped production of walnut furniture lines although some still produce mahogany furniture. Several reasons for this were cited. Among these were: the growing demand for light colored woods and finishes, the shrinking demand for high end furniture, the cost competitiveness for mid-priced furniture, the high cost of walnut lumber, and the lack of availability of adequate lengths and widths in walnut lumber.

Mahogany is a direct substitute for walnut in furniture products. And, in contrast to walnut, its use has grown slightly in traditional style furniture. Recent hardwood lumber import



Source: The Market Survey published by the Fine Hardwood Veneer Assoc. and the American Walnut Mfgers. Assoc.

Figure 12.—Percent of bedroom and dining room case goods produced of walnut, 1934-1994.

statistics reveal that mahogany imports have grown from 98.2 thousand cubic meters in 1992 to 138.9 thousand cubic meters in 1995. The current average unit price for mahogany for the first quarter of 1996, $1,650 per Mbf, is competitive with current FAS walnut lumber prices. This makes mahogany very competitive as the two species can easily be substituted for one another and mahogany is available in larger widths and lengths.

The U.S. furniture market is both large and diverse and traditional style furniture in walnut and mahogany continue to occupy a special niche. It also appears that companies that produce walnut furniture tend to specialize in its production. And, although some companies producing different distinct lines of furniture seem to have dropped walnut, walnut should remain an American tradition in finely crafted furniture.

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SPECIAL FOREST PRODUCTS: A CORNUCOPIA OF INCOME OPPORTUNITIES FOR PRIVATE LANDOWNERS

Shelby G. Jones[1]

ABSTRACT.—My paper is a brief look at the wide variety of special forest products and income possibilities available to owners of forest lands. It is meant to expand practical resource management considerations for the average forest landowner beyond traditional or conventional wood products and emerging agroforestry practices. Special forest products that can be produced and marketed by literally any forest landowner includes edible berries, fruits, and nuts; cones and seeds; medicinals and pharmaceuticals; bark; decorative wood; and mushrooms. Innovative management and marketing are the keys to special forest products.

INTRODUCTION

What a long title for such a short review paper! However, the title is indicative of the abundance of products that can be produced in just the average forest environment. Please note that I said products because markets exist for all them if a landowner is willing to search them out. In the following paragraphs I will acquaint you with a few of these special products and their market values. I believe most of you will be pleasantly surprised.

Many of you are involved in intensive management of black walnut plantations. For those of you who fit that situation, this discussion of special forest products will probably serve best to acquaint you with some new agroforestry product possibilities. However, for those of you who are managing natural stands or groves of walnut trees or other types of timber, this could be a real eye-opener.

Special forest products are special for several reasons. First, the majority of landowners do not realize there are uses, some highly specialized, and markets for many items I will mention. Second, unlike conventional forest products such as logs and firewood, special products can be harvested annually, thus yielding annual returns. Lastly, many of these products are being produced without any management assistance, investment, or even encouragement by landowners.

Many of these products have been used for years by individuals for a variety of uses. Some have had active markets for many years, but have not enjoyed widespread publicity. In a sense, modern society is currently rediscovering many historic uses and applications for a wide range of plant materials, many of which grow in forested environments. In addition, new uses are being developed, such as the use of taxol from yew bark for manufacturing a cancer treatment medicine.

SPECIAL FOREST PRODUCTS VS. AGROFORESTRY

As members of the Walnut Council and other forest organizations, most of you are keenly aware of agroforestry, possibly even implementing certain practices on your own land. At this point, you may be wondering if special forest products are not simply an integral part of agroforestry. I would like to try to make a distinction between the two, although they are definitely closely related and will probably become even closer in the future.

[1] Shelby G. Jones, Rural Development Specialist, Missouri Department of Conservation, P.O. Box 180, Jefferson City, MO 65101.

The first distinction I make is that special forest products are produced largely by natural processes without encouragement from man. It could be called nature's bounty, if you will. In contrast, agroforestry is the most intensive management regime practiced in the science of forestry. Special forest products are produced extensively rather than intensively. This is an important distinction which contributes to the practicality of the concept. Theoretically at least, if something cost less in terms of both time and money, more private landowners will be interested.

Secondly, special forest products originate from naturally occurring vegetation or conditions, whereas agroforestry may involve culture of relatively exotic crops in combination with selected and horticulturally improved native species.

Thirdly, agroforestry requires a major commitment of capital for those who wish to become involved. Special forest products may not require any capital investment and, depending on the product harvested, a minor amount of time spent by the landowner. Financial returns can be comparable for both, but generally there will be less risk with special forest product ventures.

However, it is not my purpose to convince you that special forest products offer you a better deal than the more intensive agroforestry practices or management for conventional forest products. In fact, I am hopeful many landowners will choose to become involved in all phases of forest management. The concept that I would like to emphasize is that special forest products offer a great potential for forest landowners to increase annual financial returns from their property. Annual income is rare in forestry investments and is needed to enhance investments in timber crops requiring longer production periods. Special forest products can become one way of justifying long term investments in conventional forestry. Production, harvest, and marketing of special forest products can be easily integrated with all other levels of forest management with which you are familiar.

At this point, I believe you are probably wondering if I am going to get around to specific products. In fact, I plan to do just that very shortly. I will have time to mention only a relative few of the literally thousands of different products that could be harvested and marketed. Hopefully, you will be stimulated to think of additional possibilities that fit you own situations and land capabilities.

SPECIAL FOREST PRODUCTS OPPORTUNITIES

Some reference material might be handy to help you get started. There is one publication I would recommend over all others and I would suggest you obtain a copy if you have any interest in special forest products. It is Agriculture Information Bulletin No. 666, titled Income Opportunities in Special Forest Products: Self Help Suggestions for Rural Entrepreneurs. It is, by far, the best publication I have found for both general and specific information about a wide range of special forest products. Copies may be obtained from the Forest Products Laboratory, 1 Gifford Pinchot Drive, Madison, Wisconsin 53705 or the Superintendent of Documents. In addition, many states have completed surveys of special forest products markets and uses specific to the resources of their state. Reports of the results of those surveys are generally available through the State Forester in each state. The following sections describe some of the more common special forest products, markets, and uses that can be found in the natural range of black walnut.

BERRIES, FRUITS, AND EDIBLE NUTS

Many species of berry-producing plants grow under a forest canopy. Blackberries, blueberries, goose berries, huckleberries, wild strawberries, wild grapes or maybe even mulberries are some that come to mind. Markets for landowners might be as simple as allowing picking of wild berries for a fee, picking yourself and selling the fruit to individuals, local markets, or commercial businesses for further processing. AgriMissouri, a marketing service of the Missouri Department of Agriculture, supplies a list of processors and canners who participate in their program. This list provides information needed by landowners to determine existing markets closest to them. Most other states have similar programs and services. In fact, their catalogs are excellent sources of potential markets for many special forest products.

Fruits such as persimmon, paw paw, and crab apples are used for specialty jams and jellies, confections, and baked goods. To many the fruit of Osage orange (hedge balls) is a nuisance but in fact, they have several craft applications, as do many other fruits. Many trees, shrubs, wildflowers, and grasses have fruiting structures of unusual shape or color which can be marketed for a variety of craft products, floral arrangements, or other decorative purposes. Grape vines are also popular for making vine wreaths, baskets, and other craft items. This might offer possibilities when you are releasing native walnut trees and would be killing the vines anyway!

What can I really tell readers of this proceedings about edible nuts? Even though you are focused on black walnut, I know many of you are also involved with other edible nut crops as well. On this subject, I might just remind you than many of the minor nut species also have very active markets. Hickory in the South and Midwest probably offers much potential for market expansion. Butternut, chestnut, and hazel nut are other species that might be of interest.

Acorns are most often overlooked as edible nuts in the U.S., but have much potential in international markets, especially the Pacific Rim. An individual landowner would have difficulty finding markets presently for acorns to be used for food stuff. However, in the future marketing cooperatives with the capability of marketing thousands of tons of acorns is a distinct possibility.

CONES AND SEEDS

Cones from coniferous species offer a variety of market possibilities. Since the cone contains seed, one of the most obvious markets for ripe cones is for seed to supply tree nurseries throughout the country. Cone harvest is sometimes done in conjunction with a timber sale timed to occur when the cones are ripe. Cones can then be more easily picked from the tops remaining following the removal of logs and pulpwood. There are companies who specialize in this business, who will pay a landowner for the privilege of harvesting cones. Of course, a landowner could also do this and sell cones to a seed broker or dealer. Sometimes, for specific purposes, trees are climbed to pick cones but this is best left to the professional.

Cones which have opened are also in demand for various floral, wreath, and potpourri products. Following seed extraction, many nurseries are now selling the opened cones to craft markets. Almost any species of cones, from very small fir cones to large ponderosa pine cones enjoy well-established markets. Cones are most often sold on weight basis, but may also be sold by volume (e.g., bushels) or may be individually priced for very large or unusual specimens. Prices average $0.30 to $0.60 per pound or the equivalent.

Hardwood seed crops can be handled in a similar manner. Edible nuts and their markets are quite familiar to all walnut growers. Chances are good that you are involved in producing nuts for both food and seed for growing new planting stock. While there are no edible aspects for many other species of hardwood seed, there is a growing market for seed for native plant nurseries. These nurseries are experiencing a growing demand for native plants to be used in landscaping, windbreaks, shelter belts, and other horticultural uses. Seed from under story plants and shrubs are equally desirable as the tree species. A thorough inventory of all your forest plants would be a good idea to determine if you have potential for harvesting multiple seed crops.

Prices vary directly with the relative abundance of the species and the difficulty of harvesting the seed. Price lists are available from larger seed dealers and seed supply wholesalers. Landowners could harvest seed themselves or sell harvesting rights to a seed collection company. At this point, seed certification programs do not generally exist for most species. The timing of seed harvest and care of seed following harvest are important to assure quality and maximum viability. Seed production is variable, even in local areas. For consistent income it is suggested that landowners focus on several different species and become familiar with seed production requirements for each. You should also check for special state regulations regarding the species being harvested, although there are few restrictions for harvesting on private land. For example, in Missouri there are special regulations for harvesting ginseng involving documentation of amounts harvested. The best initial contact might be your state forest nurseryman or a seed collection company for information specific to your state.

MEDICINALS AND PHARMACEUTICALS

Medicinal compounds used for naturopathic remedies include a large number of herbs used to make teas and oils that are alleged to have curative or therapeutic effects on common ailments. Actual medicinal properties are sometimes speculative; however, these markets are well established and growing.

There are, however, certain plants and trees containing specific chemical compounds used by manufacturers of pharmaceutical drugs. Wildcrafting or gathering these plants have historically provided income for many rural families. While cultivation techniques for these species will eventually assure uniformity and sustainability of harvest levels, current demands exceed supply. Agroforestry practices currently being developed offer many opportunities in this area. I have price lists available for many common medicinal plants if you are interested. Pharmaceuticals, of course, are not the only use for many of these plants. Food, dyes, cosmetics, fungicides, and insecticides are additional uses in this category manufactured from relatively common plants.

Personally, one of the more interesting special forest products is pollen from trees and shrubs which is used to produce allergenic medicines. Allergon, Inc. of Carthage, MO is a subsidiary of a large international company which purchases tree and shrub pollen throughout the world for this purpose. Their price list is also available. Pollen in generally sold on a gram weight basis. For example, basswood (*Tilia americana*) pollen sold last season for $2.00 per gram.

While pollen collection is usually accomplished with some pretty simple harvesting techniques, most landowners elect to contract with companies or individuals who specialize in pollen collection. The pollen collection season coincides with flowering in spring and early summer. As mentioned for seed collection, harvesting for conventional wood products could be timed to allow collection of flowers from the remaining crowns. If you are interested in harvesting pollen crops, I suggest you contact Dr. David Goering, a botanist with Allergon for more specific details.

BARK

Bark is another item in demand for medicinal and natural food supplements. We recently were contacted by a company in Idaho interested in purchasing 10 tons of slippery elm bark. In this case, bark is stripped from small saplings, obviously killing the trees. Sustainability is a definite problem in this case. However, landowners with slippery elm trees large enough to produce seed might consider using some of the seed to plant small plantations grown exclusively for bark production. In this case, the bark of saplings might be more valuable than logs of a mature elm tree and have a much shorter rotation. Alternatively, slippery elm could be planted as a nurse crop with walnut and harvested during the first and second precommercial thinnings.

Cottonwood bark is prized by wood carvers, who carve faces and caricatures from the thick plates. It is also used for bases for floral arrangements and crafts. It is softer than the wood, but dense enough to maintain detail. Pieces 3 to 4 in. wide, 10 to 12 in. long and 2 to 3 in. thick would sell for $5.00 to $15.00 at craft and carving shows. White and paper birch and aspen barks are also in demand for crafts, boxes, containers, and decorative uses in areas of the country where it occurs naturally. Bark with distinctive patterns (e.g., hackberry, winged elm, persimmon, etc.) or color may have a market in your area. On the negative side, sustainability can be a significant consideration for many bark products. Bark from cut logs is commonly recovered and sold for horticultural use by commercial pulpmills and sawmills.

DECORATIVE WOOD

Unusual parts of trees such as burls, conks, shelf fungus and dwarf mistletoe-infected branches are desirable for many purposes and can be sold in most areas of the country. Distorted grain patterns, colors, textures are appealing for wood turnings, veneer, carvings, or artistic sculpture. Diamond willow walking sticks from canker-infected willow are very popular. In Missouri, oak, sassafras, and staghorn sumac are harvested when 1 to 1.5 in. in diameter for walking sticks. Some have faces carved on the top, others are debarked, while many are simply cut and dried before marketing. Wholesale prices average $1.00 to $2.00 per 3 to 4 ft stick. Markets for walking sticks are far from saturated.

Cypress knees, fruitwood grafts, pine knots, knot holes, and limb crotches are more products

worth mentioning. All can be readily sold through hardwood lumber outlets, carving shops and speciality wood supply houses. A few specialty wood supply catalogs also list a variety of these types of products. Oak, hickory, and elm (with bark still attached) sticks in a diameter range of 1/2 to 1-1/2 in. are purchased for manufacture of bent-wood or rustic furniture. Fresh 4 ft sticks sell for approximately $0.50 each. Eastern red cedar and western juniper are also used for similar products.

MUSHROOMS

Wild edible mushrooms have largely been gathered and enjoyed by individuals when in season in the Midwest. Commercial wild mushroom gathering has been mainly associated with the Pacific Northwest. In fact, in both Oregon and Washington, sale of wild mushrooms to international markets annually generates several million dollars of income.

With mushrooms considered a delicacy, good areas for gathering wild mushrooms are closely guarded secrets. Trespassing on another collector's spot has generated many conflicts. While most landowners will probably elect to pick their own mushroom crop, there is plenty of opportunity to collect fees for allowing access for this purpose. Prices received by gathers for wild mushrooms vary by species and grade, but are rarely less than $1.50 per pound and as much as $6.00 per pound. It is not unusual to see even higher prices for scarce species. Knowledge of sustainability aspects is incomplete, but crops of wild mushrooms appear to be highly variable.

Demand for mushrooms is great enough to generate much interest in cultivation of species such as shiitake. This species can be grown on short, small diameter bolts of oak. White oak is preferred. Holes are drilled in fresh cut logs and wooden plugs inoculated with mushroom spores are inserted into the holes. Logs are then stacked in the woods or a controlled environment shed where they can be kept wet. Fruiting will normally occur 6 to 18 months following inoculation. A $30.00 cord of firewood can produce $400.00 to $500.00 worth of shiitake mushrooms!

Incidently, many mushroom operations eventually purchase suitable logs. If you own land close by, perhaps this is a potential market for material removed in TSI or thinning operations. Bolts are generally cut in 4 foot lengths and sell for $1.00 to $2.00 each. Since fresh cut logs are necessary for optimum production, this is a market that must be arranged prior to cutting.

RECREATIONAL ENTERPRISES

Use of private forest land for recreational pursuits offer private landowners excellent potential for annual income. The landowner has almost unlimited options in this area, from doing almost nothing to very intensive development. The old real estate adage—Location, Location, Location—certainly is true here. If your land is located near population centers, your options are probably greater than if it is in a very remote area. However, remoteness is a commodity that can be marketed also. Fee hunting and fishing have been sources of income in many areas of the country for many years. Urban families are now willing to pay for nature photography, nature study, farm vacations, hiking, photographic tours, picnic areas, and bird watching to name only few. Using the Tom Sawyer approach, I will bet you could even find a few people who would find harvesting walnuts to be an activity worth paying to participate in!

I would like to end this paper with one word of caution. Allowing public access to your private property is not without risk. Liability insurance rates vary widely for recreational enterprises. Insurance is a consideration that must be thoroughly investigated prior to any business where others are allowed on your land, especially if you are collecting fees to collect your special forest products.

SUMMARY

My paper was a brief look at the wide variety of products and income possibilities available to owners of forest lands. It was meant to expand practical resource management considerations for the average forest landowner beyond traditional or conventional wood products. Special forest products can be produced and marketed by literally any forest landowner who takes the time to assess the full range of potential. Innovative management and marketing are the keys to special forest products.

GENETIC VARIATION AND SELECTION POTENTIAL FOR BLACK WALNUT TIMBER AND NUT PRODUCTION

George Rink[1]

ABSTRACT.—Results of long-term geographic seed source tests for black walnut (*Juglans nigra* L.) are summarized, and heritability estimates for such traits as height, diameter, and nut yield are presented. Studies estimating rates of outcrossing and inbreeding and of studies estimating potential improvement in nut traits are also summarized. All studies emphasize the substantial potential for genetic selection in this species. Earlier recommendations of using southern seed sources within 200 miles of planting sites for most of the walnut range are verified; for extreme northern and northwesternmost sites local seed should be used. Biochemical electrophoretic assays of different allozymes continue to indicate that inbreeding does not seem to be a serious problem in natural stands or in close-spaced plantings. Selection for enhanced nut production appears to be effective. Trees with larger diameter nuts also have larger nutmeats; thus trees with large diameter nuts should be selected for enhanced nut bearing.

The intent of this article is to provide an overview of the latest results from genetics studies conducted by North Central Forest Experiment Station personnel at the Forestry Sciences Laboratory in Carbondale, Illinois. Most of these studies are provenance and/or progeny tests and electrophoretic studies of allozyme variation to determine mating parameters. At this symposium, Gale McGranahan and Chuck Leslie will cover the latest biotech research done on English walnut much of which will also be applicable to black walnut (McGranahan *et al.* 1997).

The earliest studies investigated the potential for exploiting geographic variation among provenances for improved growth and survival. The goal of these studies was improved timber production with little regard for nut production. One of the most comprehensive of these provenance studies consisted of seven common garden outplantings established in 1967 with seedlings from different geographic origins within the species range in the midwestern United States (Bey 1973, 1979, 1980). Each outplanting contained seedlings from at least 15 different geographic origins (Fig. 1). Survival, height, and d.b.h. measurements at age 22 revealed that trees of local origins (from within 100 miles north and south of each planting) had the best survival at all locations, and those from within 200 miles south of the planting site grew significantly faster than trees from more distant northerly origins (Bresnan *et al.* 1994). In the Minnesota and Iowa plantings, the most northwestern sites, the best survival was with seedlings of local and northwestern origins although overall survival was less than 50%.

In general, variation among trees of different geographic origins in height and d.b.h. was great and statistically significant at all planting locations (Bresnan *et al.* 1992, 1994). This implies that much of variation is under genetic control and that seed source selection should be included in black walnut tree improvement programs. Although many such provenance studies were established in the 60's and early 70's, results of the present study can be considered as generally representative of most of them. Thus

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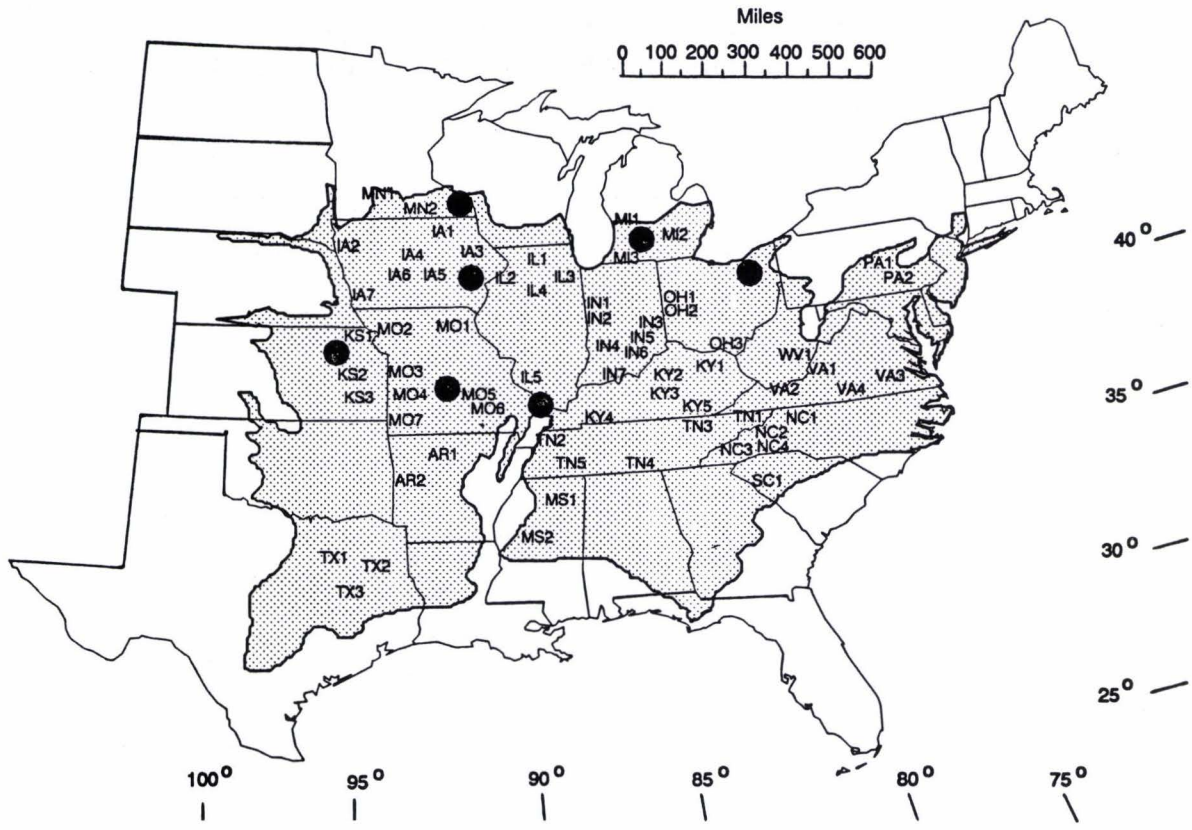

Figure 1.—Approximate natural range of black walnut is indicated by shaded area. Circles indicate plantation sites and state abbreviations represent provenances tested.

the early recommendations on planting black walnut resulting from these studies still hold. For most parts of the species range, plant material from within 200 miles south of the planting site will provide the optimum combination of growth rate and survival. The recommedation for the most extreme northern sites is to use only local plant material, since more southerly sources may not be frost hardy. Black walnut seems to be less sensitive to movement along east-west transects, although easterly sources may not be well adapted to the more arid climate of the westernmost parts of the species range.

In the next phase of genetics research, open-pollinated (half-sib) progeny tests were established to compare growth and survival of offspring (i.e., seedlings) of specific trees and to estimate heritability and gain from selection. Heritability estimates the proportion of total variation in a given trait which is under genetic control. Again, the objective of most progeny tests installed by the USDA Forest Service was to evaluate timber traits and not nut production. Nut production research for human consumption was considered to be the responsibility of the Agricultural Research Service, another USDA agency.

Although several black walnut progeny tests were installed, the progeny test most intensively studied was the Pleasant Valley test on the Shawnee National Forest in Southern Illinois (Rink 1984, Rink and Clausen 1989). The last measurement and evaluation of this test was in 1993, 20 years after establishing the progeny test. At the time, growth in the plantation was above average, and the narrow-sense heritabilities for height and diameter (d.b.h.) were 0.54 and 0.50, respectively. These heritabilities are considerably higher than for other commercially valuable tree species, and they indicate that selection and breeding can be an effective means of obtaining improved growth in future generation. These heritability values have remained relatively stable since age 8 years, indicating that selections for enhanced timber production can be safely implemented as early as age 8 (Rink and Kung 1995). Results from another progeny test established in 1980 in Southern Illinois confirm

the Pleasant Valley progeny test results (Rink and Van Sambeek 1987).

One simple approach to implementing selection is to evaluate all the trees in progeny tests, identify 5 to 10% of the trees with the fastest growth and best form, and then rogue (i.e., thin) all the remaining trees in stages. Thinning guides suggest that each thinning remove no more than 33% of a stand at any one time leaving some trees to serve as nurse trees. The non-selected trees can also serve as nut producers for reforestation efforts or be used in future studies of nut production for seed orchard management.

Nut production also appears to be under strong genetic control. In an evaluation of nut production records of 934 juvenile trees over a 7 year period, only 2% of the trees consistently produced more than 200 nuts per tree per year and only three individual trees averaged more than 300 nuts per tree per year. Eighty percent of the trees produced an average of 100 nuts per tree per year or less (Garrett *et al.* 1995). Clearly, such a variation pattern implies that nut production is under strong genetic control.

In another study of nut production, Rink *et al.* (1994) estimated heritabilities for nut yields to be 0.46 and 0.72 in 1986 and 1989, respectively. Since nut yields vary from year to year, such year-to-year discrepancies in heritabilities are not surprising. In addition, these values are based on nut production from a relatively low number of young trees; thus, they may not be very precise. Selection for enhanced nut yield appears to hold promise for nut growers; however, it should be pointed out that results also showed that increased nut yield was positively correlated with increasd growth. Apparently selection of increased growth will also result in increased nut production. Analysis of several measures of nut length, diameter, and weight, as well as kernel and shell weights from 156 southwest Missouri trees suggested that nut diameter could be used as a selection criterion for heavier nuts with larger nutmeats (Rink *et al.* in press).

Ultimately, selected trees have to be reproduced (usually by grafting) in a seed orchard. Seed orchards typically contain collections of selected trees with the objective of producing seed for reforestation. Usually seed orchards are designed to produce seed for specific geographic areas. Thus in Illinois, there are separate seed orchards for northern and southern parts of the state. Most selections in seed orchards have been for increased growth although they could be designed for other target objectives such as enhanced wood density or nut production as well. One of the common concerns of all orchards is that the clones in them routinely cross-pollinate. That can only happen if the flowering patterns of the clones are sufficiently synchronized; otherwise, nut produced could result from self-pollination or cross-pollination with only a limited number of clones. If the bulk of the clones are not reproductively synchronized, the eventual result will be the production of inbred seed. Inbreeding in trees, as with most organisms, usually results in poorer survival, slower growth, lower vigor, and decreased disease resistance. To alleviate concerns about inbreeding, geneticists commonly study mating patterns of trees in seed orchards.

The traditional approach to studying mating patterns is to physically study the timing of flower maturation and to do controlled pollinations in the orchards. The problem with that kind of work is that it is very labor intensive, slow, and expensive, especially with a species such as black walnut where each controlled pollination results in a few to no seed. Several researchers have attempted to do controlled pollinations, all have bemoaned the results (Beineke 1993). However, with the increased availability of starch gel electrophoresis techniques, an alternative approach presented itself. The technical aspects of the technique can be found in Rink *et al.* (1989) and Rink *et al.* (1994). Suffice it to say that the technique enables geneticists to study genetic variation at the individual gene level by studying variation in the enzyme systems (i.e., allozymes). Statistical analyses of results of several enzyme systems enables the projection of rates of inbreeding and outcrossing (Zuo *et al.* 1995).

In a recent study, we obtained nut collections from an Indiana Department of Natural Resources black walnut seed orchard, a Hammons Products black walnut progeny test in Missouri, and a wild (natural) population in Southern Illinois (Rink *et al.* 1994). The results indicated very high levels of genetic variablity and outcrossing rates and very low levels of inbreeding within all three types of plantings. Inbreeding levels in the seed orchard were essentially the same as in the natural population. The results

substantiate the genetic variability of black walnut as an undomesticated tree species under very little selection pressure. In contrast the Persian walnut, *Juglans regia*, from central Asia and southern Europe has undergone generations and centuries of selection by virtue of the historically greater agricultural activity within its range and show less genetic variability and higher inbreeding rates.

At this point in the evolution of black walnut culture, there are several excellent state seed orchards in existence, including those in Illinois and Indiana, among others. The Indiana orchards have reportedly started producing improved seed already. In addition, improved clones of black walnut are commercially available. Most of these have an increased timber production orientation. The development of black nut varieties is not far behind thanks to the efforts of Jim Jones and the Hammons Products Company. In spite of everyone's best efforts, I know that the seed orchards in the midwest and the selections included in them have not been adequately tested prior to the creation of these orchards. Thus, I will conclude this review by saying that there is a continuing need for long-term evaluation of existing genetic studies and of the selection that have already been made before we can say we are adequately meeting the needs of walnut growers for genetically improved planting stock.

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GROWTH DIFFERENCES AMONG PATENTED WALNUT GRAFTS AND SELECTED SEEDLINGS 12 YEARS AFTER ESTABLISHMENT

William E. Hammitt[1]

ABSTRACT.—Three sources of black walnut (*Juglans nigra* L.) stock—grafts, seed orchard seedlings, and nursery-run seedlings—were compared for growth and form differences over a 12-year period in a southwestern Ohio plantation. Growth differentials at 4-years showed the two genetic improved sources to have d.b.h. and height gains of 25 to 30% over the nursery-run material. However, the improved juvenile growth differentials were not present at the later 8- and 12-year measurements. The results are discussed in view of literature concerning age-to-age correlational growth trends and growth differences associated with geographical origins of the three planting sources.

INTRODUCTION

Black walnut (*Juglans nigra* L.) is a valued and desired tree species in the central hardwood ecosystem. Veneer logs have great commercial value and are highly desired for furniture. Black walnut, perhaps more than any other hardwood species, is intensively managed in plantations for short-rotation veneer logs. Successful plantation establishment and management is now fairly common, with growers recognizing the importance of intensive cultural practices such as weed control, pruning, thinning, and in some situations, fertilization (Beineke 1989, Braun and Byres 1982, Burde 1988, Burke and Williams 1973, Byrnes *et al.* 1973, Schlesinger 1982, Schlesinger and Funk 1977).

Also important for the production of veneer-quality logs in short-rotation management is the planting of genetically improved stock. Height and diameter (d.b.h.) in black walnut are under strong genetic control, as confirmed through heritability estimates in 15- and 22-year provenance studies (Bresnan *et al.* 1994, Clausen 1983). Possible d.b.h. and height gains of from 15 to 30% above nursery-run stock (average nursery seedlings) have been projected (Rink and Stelzer 1982), whereas Wright (1966) states that 25-year veneer log rotations are entirely possible if we start with a fast-growing variety and care for it intensively.

Although genetically improved seedlings from seed orchard sources have been recommended for more than 25 years, Beineke (1982) has advocated the merits of grafted stock from superior trees. Growth and form comparisons between 9-year-old patented Purdue #1 (USDA patent granted Purdue University) grafts and nursery-run seedlings showed net increases for the grafts of 31% in height, 29% in d.b.h., and 61% in form. Additional comparisons between other patented black walnut clones and nursery-run material at ages of 12 to 16 years showed similar percentage gains for height and diameter (Beineke 1984). Measurements at age 27 (1995 data) showed net increases for Purdue #1 grafts over nursery-run stock to be 32% for height, 22% for d.b.h. and 18% for form (Beineke 1995).

While height and d.b.h. have been shown to be under strong genetic control, it is also known that these parameters can differ with tree age, as demonstrated by juvenile and later growth estimates and phenotypic age-age correlations (Rink and Kung 1995). The purpose of this paper is to report diameter, height, and form differences for 4-, 8-, and 12-year-old plantation trees of Purdue #1 grafts, seed orchard nut-seedlings from Tennessee, and nursery-run seedlings from Missouri.

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METHODS

The study plantation is located at Harrison, Ohio, about 20-miles NW of Cincinnati. Soils consist of a Martinsville silt loam (surface layer typically 9 in. thick, subsoil about 35 in. thick), and an Eldean loam (surface layer typically 7 in. thick, subsoil about 29 in. thick). Site index for a 28-year old, 1-acre intensively managed planting directly adjacent to the study plantation suggest a value of 80+ for black walnut (Schlesinger and Funk 1977). The study plantation is approximately 2-acres in size.

In spring of 1984, grafts, nuts, and seedlings of the three sources of black walnut were planted in a fescue field. The 1-year old Purdue #1 grafts were bare-root stock, about 10 to 15 in. tall, from West Lafayette, Indiana; the field planted nuts were from a Tennessee Valley Authority (TVA) clonal seed orchard (sources from Tennessee and northern Alabama) at Norris, Tennessee; and the 1+0 nursery-run seedlings were bare rooted, about 20 to 30 in. tall, from the Missouri State Department of Conservation nursery at Licking, Missouri. A systematic planting design at 10 x 10 ft spacing was used, with the grafts planted at 40 ft intervals, the seed orchard nuts at 20 ft intervals, and the nursery-run seedlings as "spacer" trees where needed (Fig.1). In addition, a portion of the plantation contained only the nursery-run stock, thus allowing for "crop trees" at spacings of 40 and 20 ft, similar to the two genetic sources for measurement comparisons.

All sources received similar cultural treatment: sod was removed from the site (2 x 2 ft) at planting, area around seedlings were spot-sprayed twice annually for weed control with glyphosphate/simazine, mowed three times annually between rows, and fertilized annually with a 15-15-15 NPK formulation (100 lbs/acre) beginning in 1985. In 1989, these cultural practices were discontinued and crown vetch was introduced into the plantation. One annual mowing in the fall was continued to control woody plant seedling invasion in the understory. Trees in the plantation were terminally and laterally (to 13 ft) pruned annually, and the plantation was thinned in fall 1990. Only nursery-run spacer trees were removed, resulting in a 20 by 20 ft spacing between trees.

Growth and form measurements were taken in fall 1987, 1991, and 1995. Twenty-five Purdue grafts existed in the plantation and all were measured. To keep sample size among the sources approximately equal, 40 seed orchard and 40 nursery-run trees were sampled. Stem diameter was measured as 4.5 ft (d.b.h.) above the ground. Total height was measured to the nearest 1/2 ft, using measuring poles in 1987 and 1991, and with a clinometer in 1995. Stem form was determined by counting the number of terminal shoots in 1987 and by a 5-point rating scale for stem straightness in 1991 and 1995 (Beineke 1984). Differences in growth and form measurements for the three sources were analyzed by analysis of variance ($p \leq 0.05$). One-way ANOVA and Duncan's multiple range test procedures were used to test variable means (Norusis 1992).

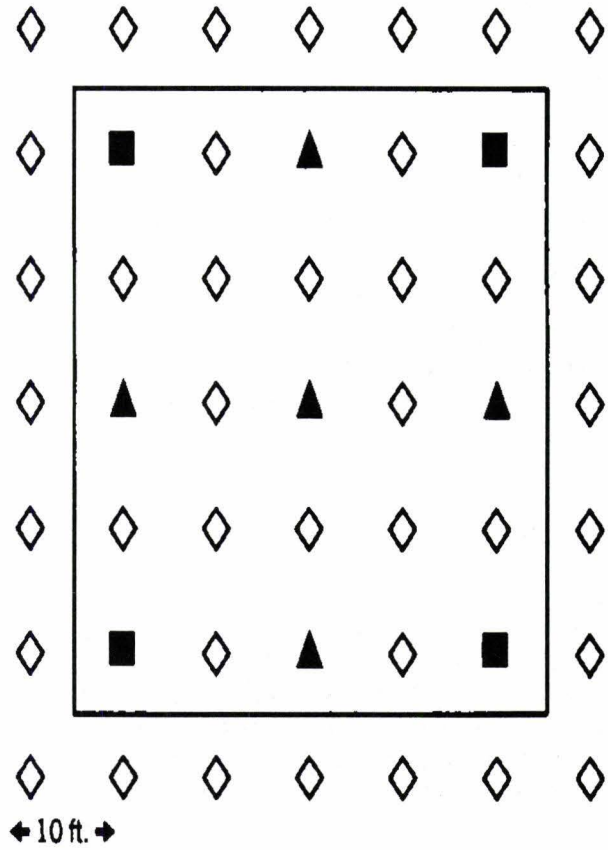

Figure 1.—Plantation design for the patented Purdue #1 grafts (solid squares), TVA seed orchard seedlings (solid triangles), and Missouri nursery-run seedings (open diamonds).

RESULTS

Diameter (d.b.h.), height, and form measurements for the three walnut sources at ages 4, 8, and 12 years are presented in Table 1. Comparison of the growth measurements for the three sources at the various time intervals follows.

Table 1.—Average diameter (d.b.h.), height, and stem form for patented graft, seed orchard, and nursery-run stock in a black walnut plantation of ages 4, 8, and 12-year (1987, 1991, and 1995, respectively)

Planting Stock	N	Diameter (in.)			Height (ft)			Form		
		1987* *	1991	1995	1987**	1991**	1995**	1987	1991	1995*
Patented graft	25	1.36a	4.01	6.08	10.82a	23.48a	35.64a	1.48	1.52	1.52a
Seed orchard	40	1.37a	4.18	6.45	10.04a	21.51b	34.23a	1.48	1.83	1.78ab
Nursery-run	40	1.06b	3.82	6.20	8.28b	20.13b	32.18b	1.63	2.08	2.05b
Percent differential between patented grafts and nursery-run stock		28	5	-2	31	17	11	10	37	35
Percent differential between seed orchard and nursery-run stock		29	9	4	21	7	6	10	14	15

* Significant difference at 0.05 level.
**Significant difference at 0.01 level.
Means by year of evaluation followed by different letters are significantly different at 0.05 level, Duncan multiple range test.

DIAMETER GROWTH RESPONSE

Diameter after 4-years of growth (1987) was significantly different ($p \leq 0.01$) between the two genetically improved sources (grafts and seed orchard stock) and the nursery-run seedlings. However, there was no significant difference between the two genetically improved sources ($p \leq 0.05$). The Purdue #1 grafts out performed the nursery-run seedlings by a d.b.h. differential increase of 28.3%, and the TVA seed orchard material showed a d.b.h. improvement of 29.2%.

After 8 and 12 years of growth, there was no significant difference ($p \leq 0.05$) among the three sources for d.b.h. The percent of d.b.h. improvement of the genetic sources over the nursery-run material decreased considerably with age of the plantation. After 12 years, the Purdue #1 grafts showed a -2% d.b.h. growth differential when compared to the Missouri nursery-run stock.

HEIGHT GROWTH RESPONSE

Height growth was significantly different among the three sources of planting stock at all three age intervals (Table 1 and Fig. 2). The Purdue grafts were taller than the nursery-run material after all three periods, while the TVA seed orchard trees were significantly taller after two of the three time periods.

The Purdue grafts and TVA seed orchard trees showed height improvements over the Missouri nursery-run trees after 4-years of 30.7 and 21.3%, respectively. Although these percent differentials decreased over the 8- and 12-year periods, the pattern of differences remained constant during the time periods (see line graphs in Fig. 2). The Purdue grafts continued to show faster height growth over the other two sources, with 17 and 11% differentials over the nursery-run stock after 8 and 12 years, respectively.

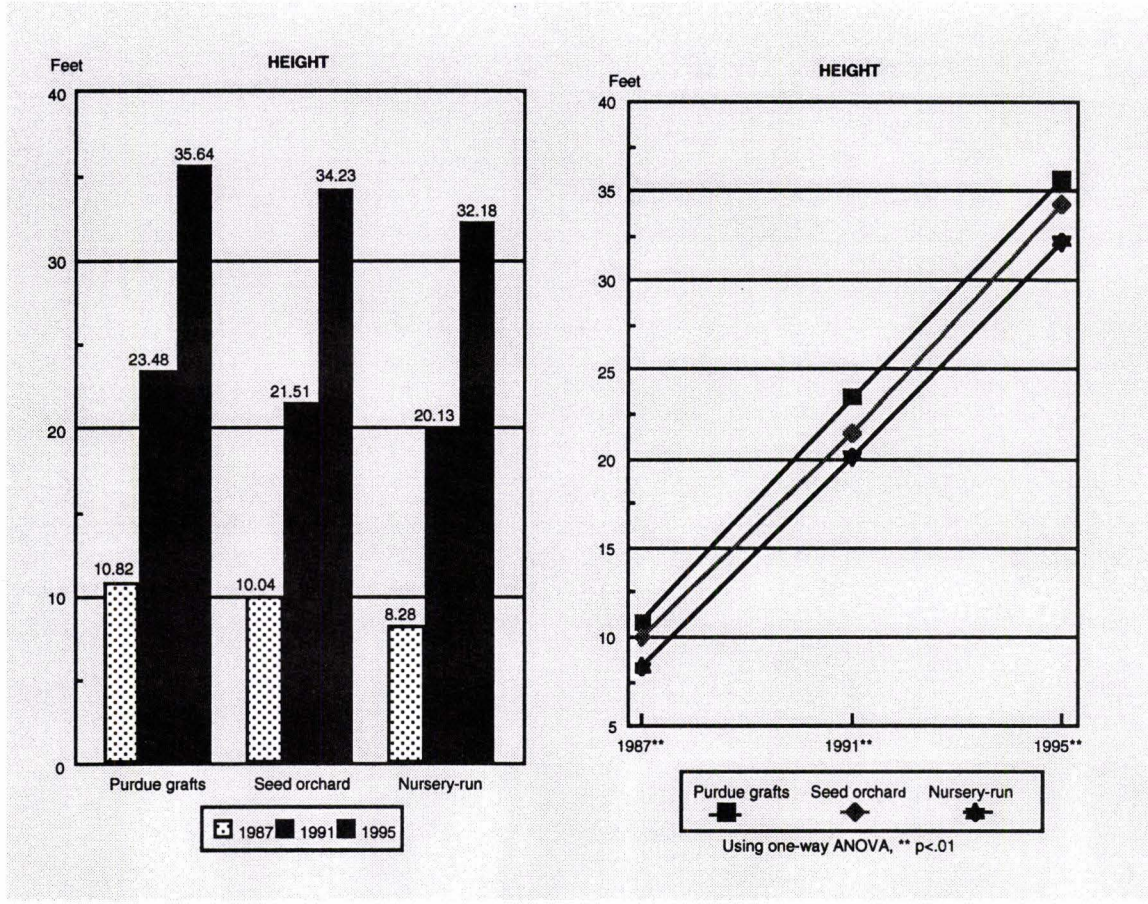

Figure 2.—Height measurements for grafted, seed orchard, and nursery-run stock in a black walnut plantation at ages 4, 8, 12 years (1987, 1991, and 1995, respectively).

TREE FORM EVALUATION

The methodology for evaluating tree form was changed between ages 4 and 8 years. However, neither of these time periods revealed a significant difference in form among the three plantation sources. A significant difference ($p \leq 0.05$) was observed after 12 years only between the Purdue grafts and the nursery-run material. The Purdue #1 grafts have better tree-bole form after 12 years of growth, showing a 35% improvement over the nursery-run trees. Form has remained quite constant for each of the sources during the 12-year period. However, the trees have been terminally and laterally pruned on an annual basis, which has reduced the amount of natural variation in form among the three sources.

DISCUSSION

The growth differentials of the two genetically improved sources over the nursery-run stock at age 4 years are quite similar to previous results (Beineke 1982). The 28% increase in d.b.h. and 31% in height of the Purdue #1 grafts over the nursery-run stock are within the 15 to 30% growth differentials projected for genetically improved material by Rink and Stelzer (1982). However, the growth differences between the genetic sources and the nursery-run stock decreased considerably after 8 and 12 years of growth. This was particularly true for diameter, where no significant differences between the sources were evident at the two later time periods. It should be pointed out that although the genetic selections did not maintain the early growth improvements, the average annual d.b.h. and height growth of 0.5 in. and 2.7 to 3.0 ft, respectively, for all three sources is comparable to Beineke's data (Beineke 1984).

Past research on the correlation of juvenile growth to later plantation growth for black walnut is mixed. Kung (1973) and McKeand (1978) have shown through age-to-age correlations that the height growth and cubic foot

volume correlations for black walnut tend to stabilize around ages 3 to 4. For example, Kung found the correlation between juvenile height and cubic foot volume at 30 years reached a plateau at age 3. However, Rink *et al.* (1982) stated that black walnut heights at 1- or 2-years of age are not good predictors of future tree size. Phenotypic age-age correlations between individual tree height at age 20 and at earlier years show that by age 8 the correlations remain fairly stable, indicating "that selection of black walnut for improved height growth could be carried out with a high degree of confidence beyond age 8 (Rink and Kung 1995)." Further research shows that "tree size at 5 years is a poor predictor of later tree growth, but performance at age 15 is more reliable (Bresnan *et al.* 1992)."

The inability of the Purdue grafts to maintain the growth advantage over the nursery-run stock may be partially explained by the geographic origins of the nursery-run seedlings. The origin of the Missouri nursery-run stock was approximately 200 miles southwest of the southwestern Ohio plantation, while the Purdue grafts originated approximately 60 miles north of the planting site. Previous research has suggested the selection of walnut seed sources within 200 miles south of planting sites in central parts of the species range will result in the largest growth gains (Bey 1980, Bresnan *et al.* 1992, Deneke *et al.* 1980). Bey *et al.* (1971) found that northern trees completed 90% of their height growth by the end of July, 15 days before the southern trees had completed 90% of their growth. The longer growing season for the Missouri nursery-run stock may partially account for the lack of growth differential of the grafts over the nursery-run stock. However, it does not explain the lack of growth difference of the TVA genetic material over the nursery-run material, as the TVA seed orchard stock originated approximately 200 miles south in Tennessee and Northern Alabama. It should be pointed out that the TVA trees were planted as nuts, as opposed to the 1-0 aged seedlings and grafts, making them technically 1 year younger than the other two sources.

One of the major attributes of the Purdue #1 grafted stock has been terminal dominance, leading to excellent stem form (Beineke 1982) and increased height growth. Stem-form gains of 37 and 35% have been maintained at ages 8 and 12 years for the grafts as compared to the nursery-run material. The strong terminal dominance of the grafts also generate a pyramidal-shaped tree crown and perhaps accounts for the significant differences in height between the grafts and nursery-run trees at each of the three measurement periods.

CONCLUSIONS

Although the 4-year growth measurements showed the two genetically improved sources to be significantly better than the nursery-run stock and to approximate growth gains projected by forest geneticists, these growth differentials were not maintained at ages 8 and 12 years. The data supports previous research that suggests early juvenile growth is a poor predictor of later tree growth in black walnut. It should be pointed out that the nursery-run stock was sorted at the time of planting so that only the larger 1-0 seedlings were planted at the crop tree spacings. This may have led to the planted seedlings going through an early period of transplant shock. Once the seedlings overcame the transplant shock they recovered the growth "lost" during the period of shock and are approximating growth rates similar to the two genetic sources.

It is also concluded that the growth differentials of this study should not be compared with Beineke's growth data for Purdue #1 grafts and nursery-run stock, since the geographic origin and associated growth-season influences of the nursery-run stock between the studies are not comparable. However, the annual average d.b.h. and height data for the grafted stock are comparable with previous studies (Beineke 1984). It appears that the genetic selections did not decrease growth during the 12 years but rather, the nursery-run stock increased in relative rate of growth.

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ALLOZYME VARIATION WITHIN AND AMONG SEVERAL *JUGLANS* L. SPECIES AND THEIR HYBRIDS

Victor B. Busov, George Rink, Scott E. Schlarbaum, and Jinghua Zuo[1]

ABSTRACT.—Allozymes are primary products of structural genes and represent direct translations of the genes. They are abundant in all living tissues and can be analyzed by simple biochemical techniques, thus providing easily accessible and readily available information about many genes. Allozyme data for 10 loci from 7 enzyme systems were compared for discriminating potential between butternut, heartnut, and black walnut. The loci for ATT-3 (asparate amino transferase), ACP-2 (acid phosphatase), and 6PG-2 (6-phosphogluconic dehydrogenase) appear to be monomorphic in butternut and heartnut and polymorphic in black walnut. An additional locus (6PG-3) not present in black walnut was found in the 6PG enzyme system of butternut and heartnut. Differences were also found in the allelic frequencies of the polymorphic loci common to the butternut/heartnut hybrid complex and black walnut. The loci for 6PG-1 and PGI-1 (phosphoglucose isomerase) appear promising for discrimination between butternut and heartnut. Calculated outcrossing rates suggest substanial inbreeding for both heartnut and butternut. In contrast, the mating system for their hybrids seemed to be predominantly outcrossing. High heterozygosity was assessed for butternut-heartnut hybrids. Despite high rates of inbreeding in butternut and heartnut, no deficiency of heterozygosity was observed. High heterozygotic estimates were assessed for the butternut trees from North Carolina. These trees are putative butternut canker resistant individuals, possibly because they are products of natural hybridization with introduced heartnuts.

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BLACK WALNUT VEGETATIVE PROPAGATION: THE CHALLENGE CONTINUES

Mark V. Coggeshall and Walter F. Beineke[1]

ABSTRACT.—Vegetative propagation techniques commonly employed for black walnut include rooting, grafting, and budding. Predictable propagation rates can be characterized as being somewhat elusive, regardless of technique. Reports of successful rooting trials indicate the importance of utilizing axillary bud-origin shoots. Grafting and budding success is dependent upon proper scionwood collection and handling, in addition to a knowledge of the effects of callusing temperature and the physiological condition of the rootstock. Micropropagation techniques for mature, elite trees remains an area of investigation that holds great promise for this species. Successful rooting of shoot tip cultures continues to be the limiting factor that prevents practitioners from fully utilizing this technology.

INTRODUCTION

Black walnut (*Juglans nigra* L.) is a tree species cultivated for its valuable nuts and desirable wood. While it is commonly grown from seed for reforestation purposes, many individuals have propagated the species by a number of traditional vegetative techniques to either maintain unique nut cultivars and ornamental varieties, or to produce selected clones for high quality timber purposes.

It is unfortunate that such a valuable tree species is so problematic, in regards to ease of propagation. Black walnut enjoys a well deserved reputation of being a "challenging" species to propagate, regardless of technique. Results from rooting of hardwood or softwood stem cuttings, grafting and budding in the field or a greenhouse, and even micropropagation techniques, have all proven to be less than optimal compared to many other North American hardwood tree species. However, progess in plant propagation has always been dependent upon the sharing of collective experiences by many individuals and indeed, some new insights are available for the species. The purpose of this paper is to describe several propagation techniques that have been used for walnut, with respect to both the physiological conditioning of the plant part used in propagation and the environmental conditions that are required to maximize propagation success.

ROOTING

The capacity of a woody plant to form adventitous roots (or "shoot borne" roots), is dependent upon a highly complex series of factors and their interactions. In general, rooting success is controlled by the following physiological and biochemical factors: plant genotype, stem maturation, and physiological status, including carbohydrate reserves, water relations, and hormonal levels (Puri and Khara 1992). The successful manipulation of these various components can only be gained through experience. Despite the inherent limitations to stem cutting propagation of black walnut, which has been described as a difficult-to-root species, some successful examples can be cited.

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The physiological condition of the donor plant can have a profound influence on rooting success and subsequent outplanting survival. For difficult-to-root species, it has been demonstrated that cuttings with a high leaf:shoot ratio (thin stems) will root in higher percentages versus cuttings with thick stems. Thin stem cuttings have a reduced carbohydrate demand for stem maintenance and therefor, will have a greater potential for survival and allocation of carbohydrates to the rooting zone during propagation (Howard 1993). Manipulation of the donor plant by means of hedging (MacDonald 1986) and/or etiolation treatments (Bassuk *et al.* 1986) have been shown to result in a greater number of thin shoots that have a reduced carbohydrate demand for stem maintenance. Farmer (1971) obtained some rooting success in black walnut by subjecting seedling stock plants to etiolation and girdling treatments. Such pretreatment of walnut stock plants is an area of study worthy of future research.

Shreve (1972) was successful in rooting black walnut softwood cuttings by utilizing shoots derived from adventitous buds, which were obtained by cutting limbs during the dormant season to force shoot growth in the spring. Truly adventitious shoots arise from unexpected locations, such as from a leaf, or from internodal stem tissue. It is much more probable that the adventitous shoots described by Shreve, arose from dormant axillary buds, which are produced at the base of each leaf as the shoot originally developed. Farmer (1973) stated that true adventitous buds do not arise from the apical meristem, or any tissue recently derived from it. More likely, the shoots utilized by Shreve, Farmer, and others were actually derived from dormant axillary buds. Both axillary and adventitous origin buds act as truly juvenile material and should be utilized in walnut stem cutting propagation of mature trees (Shreve and Miles 1972).

Softwood cuttings propagated by Shreve (1972) were made by taking cuttings when leaves were approximately 9/10th full size and the stems were at least 8 in. long. The cuttings were wounded at the base, quick dipped for one second in 8,000 ppm IBA in 95% ethanol, and stuck in a peat:perlite medium (1:1 by volume) under mist in a greenhouse. Cuttings obtained from visible buds formed callus but did not root, while those from adventitous buds rooted successfully (100%) and intiated new shoot growth within 28 days.

An explanation for the success of "adventitous bud" (dormant axillary bud) cuttings versus cuttings from visible buds was offered by Shreve *et al.* (1974). IBA was found to remain in the rooting zone for a longer period of time in the adventitous cuttings, while it was rapidly transported away from the rooting zone for the visible bud cuttings. Hess (1965) observed that while walnut softwood cuttings will root in low percentages, large amounts of callus tissue are normally formed. This callus tissue represents unorganized, yet partially differentiated cells that are common to difficult-to-root species, and may suggest the presence of a naturally occuring compound that interacts with IBA to prevent the formation of root primordia. For successful rooting to occur, callus tissue must first undergo dedifferentiation to form root primordia. This capacity to form root primordia provides the basis for classification of difficult versus easy-to-root species (Davies 1983).

A simple approach to walnut softwood cutting propagation in Texas was described by Shreve (1990) for Texas walnut (*Juglans microcarpa*). Adventitous shoots were forced from limbs cut during the dormant season and grown in containers under 50% shade. Cuttings were collected when 8 to 10 in. long when the stem base was beginning to harden. The cuttings were quick dipped in 7,000 ppm IBA in ethanol and inserted into a peat:perlite medium (1:1 by volume) to a depth of 2 in. The containers were 1/2 gal plastic milk cartons with a bottom hole for drainage. Humidity was maintained by means of a plastic bag over the top of the carton secured by a rubber band. The cuttings rooted in approximately 35 days. The plastic bag was removed after new shoot growth had reached 1 to 3 in.

Hess (1969) reported on the unsuccessful rooting of black walnut hardwood cuttings. Fall collected cuttings were soaked in 200 mg/L IBA (200 ppm) for 24 hours and callused in moist peat at 70°F in 4 weeks. The cuttings were then stored for 3 months at 41°F to break dormancy. New shoot growth developed, but no rooting occured. This procedure was modeled after traditional hardwood cutting methods for apples

and pears, and has the advantage of not requiring any greenhouse structure. Carpenter (1975) used Ethephon (an ethylene-releasing compound) in attempting to root hardwood cuttings from mature black walnuts. A 6 hour soak in 5,000 ppm Ethephon was the most successful treatment (60%). However, shoot elongation was difficult to obtain, despite additional treatments of gibberellic acid, which should have promoted shoot growth initiation following rooting.

Air layering of actively growing shoots is an additional rooting method that has been used successfully for walnut (Dirr and Heuser 1987). A girdling cut is made on the stem 1/4 to 1/2 in. wide, and root inducing plant growth regulator (such as IBA) is applied, followed by moist peat and a wrapping of aluminum foil. The layering period lasts 6 weeks and the cuttings are then severed from the plant. A high percentage of these layered cuttings will then root. This propagation method is limited due to the labor involved and the presence of suitable shoot cutting material, but it may be useful in maintaining small numbers of desirable clones.

GRAFTING & BUDDING

Perhaps the most popular, large scale, propagation method currently being employed for black walnut in the Midwest is the use of spring grafting onto potted seedling rootstocks in a greenhouse, as outlined by Beineke (1984). Predictable grafting success using this propagation method still remains somewhat elusive, as illustrated by the results obtained by member states of the North Central Fine Hardwoods Tree Improvement Cooperative (Table 1). This variation in results further indicates how the effects of personnel, greenhouse environments, plant genotypes, and scionwood handling can influence grafting success. Despite these inherent limitations, the procedure addresses the unique problems associated with this species namely, the tendency for rootstocks to "bleed", and the higher than normal temperatures that are required for successful callus formation.

Scionwood collection and storage is a critical component to grafting success. In Indiana, scions are collected during the months of January or February and stored dry in a refrigerator. It is critical that the scions are **dry** when placed into storage to avoid bud damage due to disease. No condensation should be allowed to form within plastic storage bags. In fact, scions can be stored in paper bags for up to 3 months in a cooler. Freezer storage is also possible for up to 6 months, provided that temperatures are maintained between 20 to 31°F and the scions are in plastic bags, closed with a twist tie. Prior to grafting, it is advisable to allow the scionwood to warm up in the greenhouse for approximately 1 hour, which will minimize any condensation beneath the Parafilm.

Beineke (1984) describes the following propagation method for spring grafting in a greenhouse. Large sized black walnut seedlings are potted up in February and approximately 1/3 of the shoot is removed. The rootstocks are watered in when potted but receive no further irrigation until after grafting, which can be up to 8 weeks. Grafting commences when buds on the rootstock begin to swell. One or two days prior to grafting, the top 2 in. of the rootstock are removed and observed for the presence of bleeding. If no bleeding occurs in 24 hours, then grafting can proceed.

Table 1.—Greenhouse grafting results for black walnut (*Juglans nigra* L.) by members of the North Central Fine Hardwoods Tree Improvement Cooperative

State	Year					
	1988	1989	1990	1991	1992	1993
	- - - - - -	% Success	- - - - - -			
IN	59	79	21	36	57	86
MN	43	64	63	45	45	85
MO	55	82	43	64	54	36
OH	30	72	48	67	-	-
WI	80	65	-	-	-	-

Graft carpentry is somewhat dependent upon the propagator's skill. Cleft, inlay bark, whip and tongue, and modified side grafts have been used successfully (Lowe and Beineke 1969). A recent innovation that has been employed for walnut grafting is the use of a mechanical top grafting tool, which makes smooth, wedge shaped cuts for cleft or side grafting. Less skill is required since no grafting knife is needed and more grafts can be made in a single day. Single bud scions, using healthy lateral buds from the previous growing season, are made and inserted into the corresponding cut on the rootstock. Budding rubbers are firmly (not tightly) wrapped around the graft union and Parafilm is used to completely cover all cut surfaces and the entire scion piece. Care must be exercised when wrapping the Parafilm over the scion bud, due to the tendency of walnut buds to be easily dislodged.

A nearly constant temperature within the greenhouse is one of the most important factors for success. Black walnut grafts require a higher than normal temperature regime to promote rapid callusing of the graft union, with 82°F being optimum (Sitton 1932). Daily variable temperatures between 65 and 90°F are acceptable. Disbudding of any sucker shoots arising from the rootstock should be conducted every 3 to 4 days. Under the temperature regime described, bud break of the scion should occur within 10 to 14 days. If a side graft technique is used, the remaining portion of the rootstock above the scion can be removed 10 days after grafting. The first watering of the graft since potting up is made when the leaves on the scion are approximately 1/4 full size. Weekly fertilization with an appropriate water soluable fertilizer can begin when the leaves are fully expanded. In Indiana, a time release fertilizer, such as Osmocote 17-6-12 NPK (3 to 4 month), is applied at a rate of 1 tsp per graft.

Budding rubbers are normally cut with a razor blade prior to moving the grafts outdoors after the danger of spring frosts. Grafts are hardened off under 50% shade for a period of 2 weeks, after which the shade cloth can be removed. Watering is provided on an as needed basis throughout the summer. If possible, overwintering in pots is desirable and should be in refrigerated storage at 40°F. An alternative overwintering method is to place the containers horizontal on the ground in the shade and cover with wheat straw and/or micro-foam insulated cloth and white polyethylene sheeting.

Spring bench grafting in a greenhouse is used by Hammons Products Company (Jim Jones, personal communication). Cleft grafts are made onto bareroot understocks just prior to potting up. Rootstock suckering is avoided by making the graft 3/4 in. below the root collar.

The successful use of chip budding onto potted rootstocks in a greenhouse was also reported by Tubesing (1989). During the month of May, temperatures were maintained at 75°F for callusing. Rootstocks were severely pruned when potted up and also decaptitated while in the greenhouse 4 to 6 in. above the union to force bud break. These measures helped to promote rapid callusing and growth while avoiding the problem of rootstock bleeding.

Winter bench grafting was also shown to be an effective propagation technique for *Juglans nigra* and *Juglans regia*, especially in Europe (Cerny 1965, 1969; Tsurkan and Chebotar 1972; Pieniazek 1968; Millikan 1972). Rootstocks were lifted in late fall and whip or splice grafted with scions collected in early winter. The grafts were placed in a heated bin filled with moist sawdust for a period of 3 to 4 weeks for callusing. Temperatures were maintained at 80°F. The grafts were then moved to cold storage above freezing for a period of 3 months to satisfy cold dormancy requirements. Grafts were then lined out in the field or potted up in early spring. Since both the scion and rootstock are dormant in early winter, the graft could be subjected to the high temperatures of the callusing bin without initiating bud or root growth (Cerny 1965, Harrison 1978).

Bench grafting operations have also been conducted in conjunction with a hot callus device, as developed by Lagerstedt (1981a). This device allows for rapid callusing through the use of a hot water pipe system which localizes heat only at the graft union, while both the scion and rootstock are exposed to ambient temperatures. A series of experiments using English walnut (*Juglans regia*) were made during the winter in Australia (Deering 1991). Splice grafts were made over a series of months and the best treatment incorporated the use of cooler stored scions with 4 buds in late winter. No significant differences were detected between the use of woody versus pithy scions. These results confirmed work by Avanzato and Tamponi (1988), who also used a hot callus device for bench grafting English walnut in Italy. The best timing for grafting was during the month of March.

A variation on the use of heated bins or a hot callusing device to promote callusing on winter bench grafts was conducted at the Arnold Arboretum in 1952 (R. Coggeshall, personal communication). Scions (5 to 6 in. length) were collected in December and whip grafted onto fall lifted rootstocks in early March. The completed grafts were placed in deep boxes filled with moist sawdust in a cellar for callusing. Temperatures during the callusing period ranged from 33 to 45°F. At such low temperatures, the callus development was retarded and required 8 weeks. Grafts were lined out in rows in late April. By planting the grafts to a depth of 4 in. above the graft union, no suckering occured. This propagation technique mimics work done with apples, and has the economic advantage of avoiding the need for a greenhouse and circumvents the rootstock bleeding problem inherent with spring season propagation.

Field grafting of walnut onto established rootstocks has been described by Kidd and Krause (1991). Two year old rootstocks are crown grafted in May to June. The rootstocks are cut 12 in. above the soil line 3 to 4 days prior to grafting to control any bleeding that may occur. Scions are collected in December and stored at 34°F in damp excelsior. In California, successful long term storage of scionwood for field grafting operations is dependent upon maintaining cooler temperatures between 33 and 35°F (Graves 1965). Whip and tongue grafts are made and wrapped with masking tape. The entire graft is covered with aluminum foil "tent", which allows for an extended grafting season into early July if needed. The aluminum tent is vented 14 days after grafting and is re-wrapped if the graft is still dormant. Grafts are inspected every 4 days and the foil is completely removed 3 to 4 days after venting. Aluminum foil prevents tissue dessication prior to healing of the graft union.

The use of single buds for propagating black walnuts in field situations is very popular for hobbyists and nurserymen alike. Both dormant and actively growing lateral buds may be employed and there have been numerous types of budding operations described, such as chip, patch, shield or T-buds (Jaynes 1981b). Successful outdoor propagation requires waiting until springtime day temperatures stabilize at approximately 80°F. In addition, rootstock bleeding can be problematic in certain years (Harrison 1978). For these reasons, it is common to expect highly variable results from year to year. To avoid poor success rates due to unstable springtime temperature fluctuations, walnuts can be budded in June by using greenwood buds (Davie and Davie 1977). Long (2 in.), shield buds are made as soon as growth is available, and inserted into either a T bud or coin purse cut on the stock. It is important to orient the bud on the southwest side of the rootstock for maximum heating by the afternoon sun. A portion of the leaf is retained with the bud (up to 4 leaflets). Tie in with a budding band, or waxed string, and cover with plastic sheeting or Parafilm. Inspect the bud daily and remove any dead foliage. The rootstock can be severed 4 in. above the bud if callusing has occured. Open the plastic wrapping at the bottom after callusing begins and remove the plastic wrapping after 3 weeks. Rootstock suckers should be removed as they may arise. The budding rubber may be removed after 4 weeks.

The importance of budding early in the season has been reported by several authors who state that if the bud is not forced to grow in the same year, it may die during the winter (Jaynes 1981b). In Indiana however, dormant buds can be successfully overwintered and forced to grow the following year (J. Harrell, personal communication).

TISSUE CULTURE

The use of various tissue culture technologies to produce walnut propagules continues to be an area of intense study. Sterile shoot tip cultures have been successfully produced from mature black walnuts by obtaining forced shoots from grafted trees grown in a greenhouse (Preece *et al.* 1989), from branch tips (Khan *et al.* 1995), or epicormic sprouts from branch segments (Van Sambeek *et al.* 1997).

Microshoot rooting of these shoot tip cultures remains a problem for walnut. It is partially successful when using material from juvenile stock plants (Heile-Sudholt *et al.* 1986, Long *et al.* 1995), but the rooting of explants from mature trees remains elusive, and seems to be dependent upon the actual age of the shoot tip cultures (Van Sambeek *et al.* 1997). To circumvent this rooting problem, acclimated microshoots can be successfully grafted onto seedling

rootstocks (Stephan and Millikan 1987). However, this is a very expensive alternative to traditional graft propagation. Research into the factors required to induce rooting of shoot tip cultures either *in vitro* or *ex vitro* remains the ultimate objective of ongoing studies.

In contrast to these results with black walnut, McGranahan *et al.* (1988) reported that mature clones of Persian walnuts are much easier to manipulate in tissue culture, and in fact have been successfully produced in a commercial laboratory. This variation in response to tissue culture technologies for two different *Juglans* species further illustrates the unique challenges that black walnut presents to all propagators.

SUMMARY

This review of the traditional propagation techniques employed for black walnut should illustrate a need to focus on the condition of the plant before, during, and after propagation. It is normal for this species to behave in an unpredictable manner, despite the measures taken by the propagator. It has been said that experience is the best teacher for a propagator, and while the "challenging" nature of this species is well founded, success is possible as long as attention is given to its unique requirements.

There are several promising approaches to walnut vegetative propagation. The rooting of softwood cuttings derived from axillary buds is quite successful (up to 100%), and can simply be accomplished using with ordinary milk containers and plastic bags to maintain humidity levels. Bench grafted walnuts will callus in high percentages, provided that attention is given to the timing of rootstock lifting and scionwood collection and storage. The use of a hot callus device that delivers heat only to the graft union, and not the roots or scion, should definitely increase the ability of the propagator to produce large numbers of grafts during the winter season.

Greenhouse grafting success is mostly dependent upon accurate temperature controls and proper scionwood handling. The use of a mechanical top grafting tool provides for increased efficiency in making black walnut scions and can be utilized in all types of grafting operations. Grafting or budding in field situations remains difficult, due to a reliance on suitable callusing temperatures. Perhaps more that any other technique, the success of this approach will be dependent upon the propagator's skill and location. Tissue culture technologies are being rapidly developed for the species, and while the promise of high multiplication rates for mature trees is closer to reality, additional refinements are still required at this time.

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IN VITRO ESTABLISHMENT OF TISSUES FROM ADULT BLACK WALNUT

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ABSTRACT.—Three greenhouse and laboratory techniques were used to produce softwood shoots from adult tissues of black walnut (*Juglans nigra* L.) for in vitro establishment. The first technique involved grafting scionwood from adult trees to seedling rootstocks. Although easier to maintain, cleft grafts into the taproot of quiescent seedlings were less successful and produced slightly shorter softwood shoots than stem side grafts. The second technique involved forcing 40 cm long quiescent branch tips in half-strength DKW or LP medium supplemented with 1 mM 8-HQC and various plant growth regulators to produce 1 to 2 cm long softwood shoots. The third technique involved forcing 3 to 7 cm long epicormic sprouts from latent buds on 3 to 10 cm diameter branch segments cut from the basal portion of lateral branches. Softwood shoots from all three techniques were surface-disinfested and established on DKW or LP medium supplemented with varying concentrations of BA, TDZ, and IBA. Using LP medium, less than 30% of the softwood explants produced visible exudates during in vitro establishment. With weekly to biweekly transfers to fresh medium, the terminal bud of most explants slowly elongated over a 2- to 4-month period before axillary shoots began to proliferate. The forcing of epicormic sprouts on branch segments gave the widest window of time for collecting materials. It was also the least expensive way of producing softwood shoots with little or no explant exudation thus reducing the need for rapid transfers during in vitro establishment.

INTRODUCTION

In vitro clonal propagation of elite black walnut trees (*Juglans nigra* L.) could have several advantages over the more traditional processes of budding and grafting on rootstocks of unknown genetic potential. In vitro propagation and establishment of phenotypically superior walnut trees on their own root systems would give growers genetically uniform trees with no possibility of rootstock buds replacing the selected scions as can occur with grafting or budding. Also, trees propagated from tissue taken from adult (flowering) walnut trees frequently initiate nut production sooner than trees grown from seed and seedlings. Finally, planting stock established in containers would allow for nearly year around planting (Van Sambeek *et al.* 1991). The major disadvantage to clonal propagation is the narrowing of the genetic base if too few unrelated clones (10 or fewer clones) are included in future plantings (Libby 1982).

Previous attempts to micropropagate tissues from adult trees of black walnut have been largely unsuccessful (Cummins and Ashby 1968, Lenartowicz and Millikan 1977, Somers *et al.* 1982, Huetteman *et al.* 1986). Several laboratories have reported on methods for in vitro propagation of black walnut with embryos from dormant seeds or shoot tips from greenhouse-grown seedlings (Caruso 1982, Somers *et al.* 1982, Heile-Sudholt *et al.* 1986, Stefan and Millikan 1987, Van Sambeek *et al.* 1989, Pence 1990).

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Seed, even that from superior trees, shows substantial genetic variation and most of the seed will not carry all the desired traits of the mother tree. Cotyledons of immature black walnut seeds have been used for successful somatic embryogenesis and organogenesis (Cornu 1988, Neuman *et al.* 1993, Long *et al.* 1995). Besides the inherent genetic variation from using seed, additional genetic variation can occur when adventitious embryogenesis or organogenesis (Skirvin *et al.* 1994).

Several reports of successful micropropagation of adult tissue from species related to black walnut do exist (McGranahan *et al.* 1988, Rodriquez *et al.* 1989, Preece *et al.* 1989). Failure to propagate adult black walnut has primarily been because of microbial contamination of field-grown tissues (Stefan 1989, Preece *et al.* 1989) and the production of toxic exudates within hours of in vitro establishment (Heile 1985, Huetteman 1988, Preece and Compton 1991). Other causes have included latent contamination by slow growing bacteria or a slow decline of established cultures resulting from an improper balance of nutrients and plant growth regulators (Lenartowicz and Millikan 1977, Rodriguez *et al.* 1989, Meynier and Arnould 1991, Preece 1995).

Production of toxic exudates is thought to occur primarily in response to wounding, handling during surface disinfestation, the disinfesting agent, nutrient imbalance, sucrose concentrations, or the incorrect choice of plant growth regulators (Preece and Compton 1991). Although presoaks in sterile water or medium for 1 to 12 hours have been used to reduce exudation, it has done little to solve the problem (Rodriguez 1982, Compton and Preece 1986, McGranahan *et al.* 1987, Stefan and Millikan 1987). A high salt culture medium such as Driver-Kuniyuki-Walnut (DKW) medium has been shown to be superior to a low salt medium like Woody Plant Medium (WPM) for in vitro establishment of most *Juglans* spp. (Somers *et al.* 1982, Driver and Kuniyuki 1984, Tuleke and McGranahan 1985, McGranahan *et al.* 1987, Pijut 1993). Recently, Khan *et al.* (1995) showed that Long-Preece medium (LP), a medium with equal proportions of DKW and WPM salts, was far superior in reducing exudation than either DKW or WPM. Several studies have shown a strong correlation between nutrient balance and plant growth regulator concentrations essential for the successful establishment of black walnut and other hardwoods (Rodriguez *et al.* 1989, Preece 1995, Khan *et al.* 1996). Other studies show that rapid transfers to new medium is more effective than the use of antioxidants like polyvinylpyrrolidone (PVP), ascorbic acid, 8-HQC or Na-DIECA for controlling toxic exudates (Somers *et al.* 1982, Compton and Preece 1986, Stefan and Millikan 1987).

The early development of trees grown from seed includes a juvenile phase during which time flowering cannot occur (Hackett 1985). Most trees eventually undergo a transition from a juvenile to an adult phase characterized by progressive physiological changes leading to the regular production of flowers under natural conditions. Phase change may be controlled by many factors including genetics, growth rate, size, nutrition, and environmental conditions. The loss of juvenile characteristics also results in decreased ability to form adventitious roots, a condition needed to vegetatively propagate most woody plants. Growth regulators such as gibberellins or cytokinins may also influence phase change. One of the most effective plant growth regulators for hardwood micropropagation has been thidiazuron (TDZ), a cytokinin-analog associated with meristematic activity and delayed senescence (Huetteman and Preece 1993).

Successful in vitro establishment of plant tissue from adult trees normally involve selecting tissues that exhibit juvenile characteristics or that can revert to a more juvenile condition (Hackett 1985, Thorpe *et al.* 1991). Research has shown that tissue near the base of plants retain more juvenile characteristics than tissue near the periphery of the plant (Shreve 1974). Cuttings taken on branches in the upper part of the crown show less juvenility than those from the lower part of the crown. Epicormic shoots produced from latent buds near the base of the trunk and primary branches often possess more juvenility than other tissue on adult trees (Bonga 1987). Recently, branch segments were used to produce epicormic sprouts for in vitro establishment and rooting of several recalcitrant hardwoods (Ikemori 1987, Cameron and Sani 1994, Vieitez *et al.* 1994). Techniques for rejuvenation include hedging (Leslie and McGranahan 1992), partial etiolation (Ballester *et al.* 1990), application of plant growth regulators (Ballester *et al.* 1990), grafting to juvenile rootstocks (Francelet *et al.* 1987, McGranahan *et al.* 1988, Juncker and Favre 1989, Leslie and McGranahan 1992), and in vitro propagation with horizontal subculturing (Navarrete *et al.*1989, Ballester *et al.* 1990, Vieitez *et al.* 1994).

Our objectives for this paper are to describe recent experiments designed to obtain explants from grafted seedlings, from forced branch tips, or from epicormic sprouts on branch segments for subsequent in vitro establishment and proliferation. We conclude this review paper on adult black walnut micropropagation by discussing problems that still need to be addressed before we can successfully clone elite black walnut.

EXPLANTS FROM GRAFTED SEEDLINGS

Scionwood was obtained from 11 adult black walnut cultivars selected for their growth, nut, or wood property characteristics. Seedlings (45 to 60 cm tall) for rootstocks were obtained from a wholesale nursery in Tennessee. Half of the seedlings were planted in 15- x 60-cm long stovepipes filled with a 1:1:1 mix of decomposed hardwood bark mulch, pinebark mulch and Promix® and placed in the greenhouse on May 9. The other half of the seedlings were packed in moist sphagnum peat and refrigerated (4 to 10°C) until June 2 when all seedlings were grafted.

For each cultivar, two to eight seedlings were side grafted using procedures described by Bieneke (1983) or Van Sambeek (1989). The basal 3 to 5 cm of an 8- to 10-cm long piece of scionwood was cut to form a wedge below two quiescent buds. A 3 to 5 cm long cut was made into the stem of the rootstock in a region of similar diameter as the scionwood. The scionwood was forced into the slit, matching cambiums on both sides before wrapping the union with a budding band and the entire graft with Parafilm®. New rootstock growth was retained for 2 weeks before the stem was cut off 3 to 5 cm above the graft union. Thereafter, emerging lateral buds on the rootstock stem were removed weekly until a lateral bud from the scion pushed through the stretched film.

For the 11 test cultivars, scionwood of each was also cleft grafted into the taproot of 2 to 13 quiescent seedlings. For this graft, the stem and root collar were removed 1 cm below the root collar before making a 5-cm deep vertical cut into the top of the taproot. An 8- to 10-cm long, wedge-shaped piece of scionwood with two quiescent buds was forced into the slit so that cambiums matched along one side of the taproot. Graft unions were tightly closed with a budding rubber and completely covered with Parafilm®. Grafted taproots were planted in stovepipes so the graft union was 1 cm deep in the same soil mix as the rootstocks for the stem side grafts.

Each graft was watered with 250 ml of a ROOTS® solution (1 oz concentrate in 4 L water) to enhance early root development (James E. Jones, personal communication). Grafts were placed under a greenhouse mist system set to provide 1 hr of daily misting at sunrise. Misting was stopped 8 weeks after grafting. Pots were then watered from below to keep the surface of the scionwood shoots dry and reduce the growth of bacteria and fungi on elongating shoots.

Eight weeks after grafting, the percentage of grafts with elongating shoots was similar for scionwood from adult (nut-producing) trees and for transitional (beginning to produce flowers and nuts) walnut trees (Table 1). The percentage of successful grafts was higher for stem side grafts (46%) than for the taproot cleft grafts (38%). In addition, the softwood shoots on the stem side grafts were nearly twice as long with nearly twice as many leaves as the shoots on the taproot cleft grafts. On most of the unsuccessful taproot cleft grafts, failure was related to settling of the potting medium leaving the graft union above the soil line or storing the completed grafts overnight in a cooler before planting.

Statistically, no differences were found in shoot growth between scionwood from adult and transitional walnut trees. The major advantage of the taproot cleft graft was that only the successful grafts produced softwood shoots, thus eliminating the possibility of mistaking growth from the rootstock as growth from the scionwood.

On August 3, 10, and 30, scionwood shoots greater than 3 cm long were excised between the second and third basal leaf. In addition, elongating shoot tips on unsuccessful grafts were cut to serve as a seedling control. Leaf tissue, excluding 0.5 cm of the petiole, was excised before placing shoots individually in labeled culture tubes containing sterile LP liquid medium for 1 to 2 hours (Lloyd and McCown 1981). Shoots were surface disinfested for 15 to 30 minutes in 0.6% sodium hypochlorite with two drops Tween 20® per liter, followed by three 5 minute rinses with sterile distilled water before the addition of sufficient sterile LP liquid medium supplemented with 3% sucrose, 0.3 mM TDZ, 0.05 mM IBA, and 1 mM BA to cover all but the terminal bud.

Table 1.—Grafting success, new shoot length, and number of leaves 8 weeks after grafting adult or transitional black walnut cultivars using either stem side grafts or taproot cleft grafts

Maturity level and cultivar	Stem side grafts				Taproot cleft grafts			
	Number of grafts	Takes	Shoot length	Number of leaves	Number of grafts	Takes	Shoot length	Number of leaves
		%	*cm*			%	*cm*	
ADULT TREES								
Purdue # 1	8	50	9.0	8.7	4	25	0.5	2.0
Tippecanoe #1	5	40	4.0	6.5	6	17	0.5	1.0
Thomas	2	50	1.0	6.0	3	100	2.5	4.7
Davidson	3	67	8.8	10.0	2	50	2.5	6.0
Sparks 127	3	67	7.7	8.0	2	0	—	—
Cutleaf	2	0	—	—	2	50	6.0	9.0
Average	—	46	6.1	7.8	—	40	2.4	4.5
TRANSITIONAL								
HRDA # 1	5	60	4.3	6.3	3	0	—	—
HRDA # 2	5	60	7.2	8.7	3	0	—	—
FSL # 1	7	29	1.8	5.0	5	60	3.5	4.0
FSL # 2	5	40	3.3	8.0	6	33	1.8	6.0
FSL # 3	5	40	7.2	9.0	13	85	3.5	5
Average	—	46	4.8	7.4	—	36	2.9	5.2

Within 24 hours following in vitro establishment, nearly all explants were still yellow-green to green and had produced a small amount of exudate at the bottom of most culture tubes (Table 2). When shoot color was scored (0 for all tissues brown to black to 3 for green to dark green tissues), explants from scionwood of transitional and adult walnut trees showed less discoloration than explants from 1-1 seedlings. When precipitate color was scored (0 for visible grey precipitate to 3 for clear medium without a precipitate), explants from seedlings produced fewer visible exudates than explants from scionwood. Amounts of exudation were similar for explants from transitional and adult trees and for both types of grafts. Unlike past studies, exudates did not rapidly form causing explant death and frequent transfers to fresh medium were not necessary.

Table 2.—Explant length, index of explant and precipitate color after 24 hours in vitro, number and combined length of new leaves 2 and 4 weeks after in vitro establishment for explants from seedlings and grafts of transitional and adult walnut trees

Explant source	Type of graft	Explant length	24 hr. in vitro		2 weeks in vitro		4 weeks in vitro	
			Explant color	Prec. color	No. of Leaves	Length of leaves	No. of Leaves	Length of leaves
		cm				*mm*		*mm*
Seedlings	None	4.3	2.4	1.8	2.7	32	5.3	108
Transitional	Side	4.6	2.5	1.5	2.6	30	3.0	41
Transitional	Root	4.1	2.5	1.6	1.9	19	2.9	47
Adult trees	Side	4.9	2.6	1.2	2.0	18	2.5	45
Adult trees	Root	4.6	2.6	1.5	2.0	18	3.8	50

After 2 weeks in culture, most explants had one to three leaves with a combined average length between 19 and 32 mm (Table 2). Explants from grafts made from walnut trees in transition or adult trees looked similar to those from seedlings after 2 weeks in vitro; however, explants from seedlings had developed more leaves with a greater combined length than explants from grafts after 4 weeks in vitro. No significant differences were found for explants taken from side grafts or taproot cleft grafts for either number or combined length of leaves after 2 or 4 weeks in vitro. Results suggest that rejuvenation was sufficient to establish most explants in vitro if established on LP medium.

Between 30 and 40% of the explants were discarded within 1 week because they were rapidly overgrown by fungal or bacterial contaminants (Table 3). Explants from taproot cleft grafts had contamination rates similar to explants from stem side grafts or seedling shoot tips. Between 20 and 40% of the explants were discarded because exudation could not be controlled, resulting in their death. With walnut, once browning of the explant occurs, it is extremely difficult to reverse further decline (Preece and Compton 1991). After 4 to 6 weeks contamination-free explants were placed horizontally on agar-solidified LP medium in GA7® culture boxes. Two weeks later, a 2-to 3-mm deep overlay of liquid LP medium was added to accelerate elongation of lateral buds. Following the addition of liquid overlays, small white halos developed at the base of the explant if not transferred to new medium for 2 weeks or more. Meynier and Arnould (1989) observed similar endophytic bacterial contaminants from established cultures. We have been unable to eliminate the bacterium with antibiotics such as rifampicin without death of the explant.

Our results showed that grafting of scionwood from adult trees onto seedling rootstocks under greenhouse conditions can be used to produce softwood explants for in vitro establishment. Although new shoot elongation is slower, we recommend cleft grafting scionwood into the taproot of quiescent seedlings because it requires less aftercare in the greenhouse. Although grafts were grown in the greenhouse, approximately 30 to 40% of the surface-disinfested explants from the softwood shoots were quickly contamination from fungi and/or bacteria. Likewise, approximately 30 to 40% of explants started to decline within 4 weeks of establishment. Declining explants initiated rapid exudate production which eventually killed the explant. Of the remaining explants, eventually all became visually contaminated within 2 to 8 weeks of establishment by a white, slow-growing, endophytic bacterium and were discarded.

EXPLANTS FROM FORCED BRANCH TIPS

Quiescent branch tips 50 cm long were cut from the lower and mid canopy of 11- and 23-year-old black walnut trees from two nut-producing stands with a crownvetch ground cover. Branch tips were collected from November thru April, wrapped in moist paper towels, and placed in plastic bags. Branches were used the same day or refrigerated at 5°C until needed. Before placing branches in the test forcing solutions, they were surface disinfested for 15 minutes in 0.8% sodium hypochlorite with 1 ml Tween® per liter of distilled water, and rinsed prior to cutting

Table 3.—In vitro establishment length and percentage of explants lost to initial contamination, exudation, and endophytic bacterial contamination

Explant source	Type of graft	Number of explants	Average number of days till discarded	Percentage of cultures lost to: Initial contamination	Decline and exudation	Endophytic bacteria
Juvenile	None	13	27	38	16	46
Transitional	Side	15	25	33	40	27
Transitional	Cleft	22	21	36	28	36
Adult	Side	13	22	38	31	31
Adult	Cleft	13	24	38	31	31

under running water to 40 cm lengths to retain an average of 25 to 30 quiescent buds. For most forcing experiments, 0.5 L of the test solution (50 mm deep) was added to each 2-L glass jar. There were five stems per jar with five jars per treatment, test solutions were changed every 2 or 3 days at which time stems were recut under water to remove a 1 cm long cross-section from the basal end. Forcing studies were conducted in the laboratory growth room under cool-white fluorescent lights (50 $\mu mol \cdot m^{-2} \cdot sec^{-1}$) with a 16-hr photoperiod.

A series of experiments was completed testing various combinations of water, half-strength DKW medium, or half-strength LP medium (without organics, iron, or sucrose) supplemented with 1 mM 8-hydroxyguinoline citrate (8-HQC) and plant growth regulators at different concentrations (Khan 1995). Results from each experiment with the same treatment were combined.

Overall, branches forced in a half-strength DKW medium produced longer terminal buds with a higher percentage of elongating lateral buds than branches forced in half-strength LP medium with the same concentration of plant growth regulators (Table 4). These differences may be due to dormancy and the number of chilling degree days. Branches forced in DKW medium were cut in late spring when quiescent; branches forced in LP medium were cut in late fall when dormant. New growth on branches forced in solutions with 1 mM 8-HQC was usually longer and remained green longer than new shoots forced on branches in solutions without 8-HQC, especially if sucrose had been added to the forcing solutions (data not presented). Additions of sucrose proved unnecessary and usually resulted in cloudy forcing solutions and greater microbial contamination of plant tissue (Khan 1995).

Thidiazuron (TDZ) had a greater effect on terminal shoot growth and number of elongating lateral shoots than either BA, kinetin, or gibberellic acid (GA_3) (Table 4). The optimum concentration was between 0.1 and 1.0 µM TDZ in the forcing solution for dormant and quiescent branches. Dormant branches cut in late fall or winter also appeared to benefit from the addition of 10 µM GA_3 to the forcing solution. The cytokinins, kinetin, and BA had little effect when added at 10 µM concentrations to the forcing solutions.

When terminal or lateral shoots on forced branches exceeded 2.5 cm in length, these shoots were excised and surface disinfested.

Table 4.—Effects of different forcing solutions and plant growth regulators on terminal and lateral bud growth of forced branch tips from adult black walnut trees

Forcing solution	Plant growth regulator	Growth regulator conc.	Number of shoots treated	Terminal shoot length	Elongating lateral shoots	Percent of all buds elongating
		µM		*cm*	*#*	*%*
Water	None	——-	20	1.1	0.5	1.7
1/2 LP	BA	10 µM	50	——-	0.6	2.3
1/2 LP	None	——-	400	0.5	0.5	1.5
1/2 LP	GA3	10 µM	240	1.0	0.9	3.3
1/2 LP	GA3	20 µM	40	0.5	0.8	3.7
1/2 LP	Kinetin	10 µM	50	——-	0.1	0.4
1/2 LP	TDZ	1.0 µM	100	——-	0.5	1.7
1/2 LP	TDZ	10 µM	210	0.5	0.7	3.0
1/2 DKW	None	——-	60	1.6	0.8	3.7
1/2 DKW	TDZ	0.01µM	50	1.6	1.6	5.6
1/2 DKW	TDZ	0.1 µM	50	1.7	1.7	5.9
1/2 DKW	TDZ	1.0 µM	50	1.7	1.5	5.8
1/2 DKW	TDZ	10 µM	50	1.6	1.7	6.4

Shoots were placed on agar-solidified DKW medium supplemented with 3% sucrose, 5 μM BA, and 0.05 μM IBA or on agar-solidified LP medium supplemented with 3% sucrose, 1 μM TDZ, 5 μM BA, and 0.05 μM IBA. The same medium was used to determine if plant growth regulators in the forcing solutions had any carryover effects during in vitro establishment. After 6 to 8 weeks in culture, explants were placed on medium supplemented with 1 μM TDZ to stimulate axillary shoot proliferation and growth. When 1 μM TDZ was not included in the culture media, significant carryover effects of TDZ in the forcing solutions were found (Table 5). Shoots produced without TDZ in the forcing solution rapidly declined when placed on the culture medium without TDZ.

Our results show that forcing 40 cm long branch tips from adult trees can produce terminal and/or lateral shoots suitable for production of explants for in vitro establishment. Branch tips were most responsive when cut in the spring during the quiescent period. Results suggest branch tips should be forced in LP medium supplemented with 1 mM 8-HQC and 0.3 μM TDZ without iron, organics, or sucrose. Results also showed that forced shoots initiated in vitro grow more rapidly on LP medium than on DKW medium. There are several disadvantages of forcing new growth on branch tips as a source for in vitro explants. It is labor intensive because branches need to be recut and placed in new solutions 2 to 3 times a week. There is a narrow window for collecting quiescent branches because dormant branches cut in the fall and winter have chilling requirements that cannot be met with refrigeration. The major advantages of forcing new growth on branch tips were that multiple explants could be produced from each quiescent branch tip and harvesting a few branch tips from an adult tree is unlikely to adversely affect its growth.

EXPLANTS FROM EPICORMIC SPROUTS ON BRANCH SEGMENTS

For a 12 month period, one primary branch was pruned from the lower crown of three 30-year-old walnut trees growing at the Tree Improvement Center arboretum maintained by the USDA Forest Service. All trees were planted as grafted seedlings of the nut cultivars ('Sparrow', 'Farrington', 'Stanbaugh', 'Vandersloot', and 'Victoria'). After removing secondary branches, four 32 cm long branch segments were cut from the basal end of each branch and labeled as to tree and position on the branch. Branch segments were sprayed with a pyrethrin-based insecticide and placed horizontally in shallow plastic trays filled with horticultural grade perlite (Fig. 1). Trays were maintained at 22°C with a continuous photoperiod (30 $\mu mol \cdot m^{-2} \cdot s^{-1}$) from

Table 5. —Carryover effect of forcing medium and plant growth regulators after 6 to 8 weeks for nodal segments cut from elongating shoots on forced branch tips of adult black walnut trees

Forcing solution			Number of explants	Green explant length	Number of leaflets	Length longest leaflet	Number of axillary buds	Callus volume
Solution	PGR	Conc.						
		μM		*cm*		*mm*		*cm^3*
1/2 LP	TDZ	10.0	10	1.3	29.3	11.0	7.8	9.0
1/2 LP	None	——-	15	1.0	25.1	23.3	2.8	9.7
1/2 LP	TDZ	1.0	3	0.8	53.0	5.7	11.0	9.1
1/2 LP	GA3	10.0	7	1.8	25.6	20.0	3.1	9.3
1/2 LP	BA	10.0	2	1.0	7.5	7.5	2.0	5.0
1/2 LP	Kinetin	10.0	3	0	0	——	6.0	3.2
1/2 DKW	None	——-	17	0	0	——	0	0.2
1/2 DKW	TDZ	0.01	18	0.5	n.d.	n.d.	n.d.	0.2
1/2 DKW	TDZ	0.1	9	1.4	n.d.	n.d.	n.d.	9.8
1/2 DKW	TDZ	1.0	8	0.8	n.d.	n.d.	n.d.	0.6
1/2 DKW	TDZ	10.0	17	1.0	n.d.	n.d.	n.d.	3.1

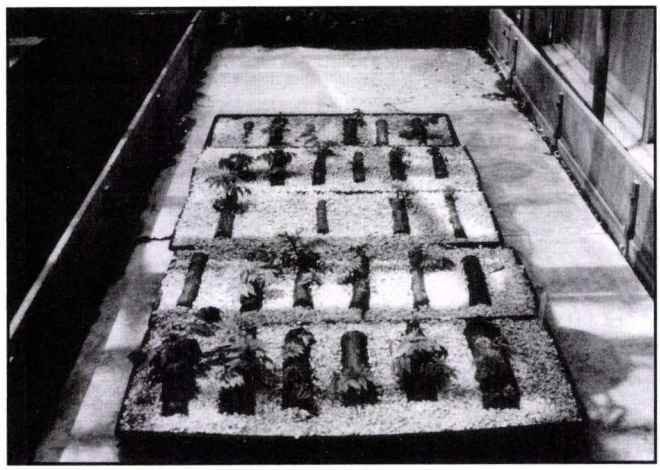

Figure 1.—Forced epicormic sprouts on branch segments in trays of moist perlite.

cool white fluorescent lights. Branch segments were soaked briefly each day with tapwater taking care not to wet emerging or elongating epicormic shoots from lateral buds. Data recorded from branch segments included collection dates, days to emergence of first epicormic buds, date of shoot excision, and epicormic sprout length (Table 6).

Branch segments cut early in the dormant season (October - December) exhibited dormancy and produced few if any visible buds or epicormic sprouts of sufficient length for use in in vitro culture (Table 6). After 90 days of cold hardening in the field, branch segments were quiescent and started producing a small number of buds that elongated slowly under laboratory conditions. By March, most branch segments produced one or more harvestable epicormic sprouts within 3 to 5 weeks. From March thru September more than 80% of the segments produced 1 to 5 harvestable shoots. Most epicormic shoots were between 30 and 40 mm long before elongation rates declined and shoots were harvested for in vitro culture. There was no significant differences in the number of epicormic shoots produced either for the walnut cultivar or position of branch segments along the branch.

From May to August, branches were also cut from three trees in the transition phase (FSL # 1, FSL # 2, and FSL # 3). In general, branch segments with more juvenile characteristics were more responsive than branch segments taken from adult trees. Branch segments from transitional trees tended to produce visible buds 9 days sooner than branch segments from adult trees. The epicormic sprouts from the transitional trees also produced longer and more vigorous shoots before elongation rates declined (data not presented). Unlike explants from the adult cultivars, explants from transitional trees, especially FSL # 2, produced visible exudates making them more difficult to culture.

Table 6.—Number of visible buds, epicormic sprouts> 2 cm long, and of sprouts from previously harvested epicormic sprouts from four 30-cm long branch segments cut monthly from three trees

Julian date of harvest	Segments w/sprouts	Emergent buds	Harvestable shoots >20 mm	Primary shoot length	Days to shoot > 20 mm in length
	- - - - *Number* - - - -			*mm*	
272, 1994 (Oct)	1	3	1	34	41
304, 1994 (Nov)	0	0	0	——	——
335, 1994 (Dec)	0	0	0	——	——
03, 1995 (Jan)	5	5	9	32	50
34, 1995 (Feb)	2	8	7	38	40
61, 1995 (Mar)	8	32	18	37	32
89, 1995 (Apr)	6	24	25	45	29
123, 1995 (May)	11	21	22	40	26
157, 1995 (Jun)	2	5	0	——	——
186, 1995 (Jul)	9	21	16	32	25
216, 1995 (Aug)	9	22	11	34	28
249, 1995 (Sep)	7	16	12	39	30

Epicormic shoots were harvested when they exceeded 2.5 cm in length and daily elongation rates declined. Shoots were excised above the second leaf, leaving several basal buds for additional shoot development. Leaves were removed from harvested shoots leaving 0.5 cm long petioles prior to placement of shoots in 25 x 125 mm culture tubes. Shoots were surface disinfested for 20 minutes in 11% bleach followed by three 5-minute rinses in sterile water. Sterile LP liquid medium supplemented with 3% sucrose, 0.3 µM TDZ, 0.05 µM IBA and 1 µM BA was added to each culture leaving 1 cm of the shoot tip exposed above the liquid.

Forcing of epicormic sprouts on branch segments in the greenhouse has several advantages over other techniques for producing in vitro explants. Forcing epicormic sprouts on segments from branches in the lower crown makes it unnecessary to radically prune or fell selected trees to force growth of epicormic or water sprouts on coppiced stems. In addition, forcing is done in the greenhouse reducing contamination of explants. Shoots from branch segments possess more juvenile characteristics than shoots from grafted seedlings or forced on branch tips. Increased juvenility may enhance in vitro explant establishment, axillary shoot multiplication, and microshoot rooting.

IN VITRO EXPLANT ESTABLISHMENT AND PROLIFERATION

Following surface disinfestation, explants from grafted seedlings, forced branch tips, and epicormic sprouts were placed in culture tubes to initiate the establishment phase on one of three liquid culture media supplemented with various concentrations of TDZ, BA, and IBA. Liquid medium was adjusted to a pH of 5.8 prior to autoclaving at 121°C and 108 kPa for 20 to 60 minutes depending on volume of medium in each vessel.

During initial establishment, explants were transferred to new liquid medium every 2 days over a period of 2 weeks. After that explants were routinely transferred to new medium at weekly intervals until explants began rapidly growing. Depending on the source of the explant and cultivar, explants remained in culture tubes for up to 4 weeks. During this time cultures were incubated in a constant temperature climate-controlled laboratory at 22°C under cool-white fluorescent lights (30 $\mu mol \cdot s^{-1} \cdot m^{-2}$) with a 16-hour photoperiod.

To provide room for adequate leaf development and discourage apical dominance, established explants were placed horizontally on solid medium in GA7® boxes. No new leaves were excised from proliferating explants during transfers. When leaves were partially or completely removed, explants were less vigorous and showed a greater tendency to produce callus than explants without cut or damaged leaves. McGranahan *et al.* (1988) also observed a similar occurrence with *J. regia* shoots. We took care to keep wounding of explants to a minimum, removing tissue only if it were dead or when it could be easily separated from the healthy tissue without wounding. The periodic excision of shoots for subculturing was not done because it resulted in a decline of the explants in response to wounding. Callus was removed biweekly; however, its removal did not appear to affect the explant as much as removal of leaves or axillary shoots. Cultures were transferred weekly for the first 4 to 6 weeks, then biweekly thereafter as the rate of toxic exudates released into the liquid medium decreased.

The decision to maintain the cultures on agar-solidified medium with liquid overlays was made when the cultures maintained on agar-only looked desiccated. Initially we tried to correct the desiccation by decreasing agar concentration to between 0.4 and 0.5%; however, over time this did not correct the problem. To provide a means of anchoring proliferating cultures in preparation for the liquid overlay, 25 ml of LP medium supplemented with 3% sucrose, 0.5% casein hydrosylate, and 0.6 % Difco-Bacto® agar was added to the GA7® boxes. The liquid overlay consisted of LP medium with 3% sucrose and the addition of various concentrations of TDZ, BA and IBA depending upon the desired growth response. The amount of liquid added to the cultures was dependent on the size of the explant, best results were achieved if the liquid covered the lower half of the proliferating mass of shoots.

Shoot tip explants established on LP supplemented with TDZ usually initiated terminal shoot growth before lateral bud enlargement and elongation. Although lateral bud elongation and axillary shoot proliferation rates were not determined; however, one shoot tip from the 'Sparrow'

cultivar after 12 months in vitro had been propagated into 16 GA7® boxes (Fig. 2). Each box contained tissue masses with 10 to 30 axillary shoots from 0.5 to 5 cm long. Most axillary shoots, however, were relatively short (<2 cm long) and frequently were faciated in response to the high TDZ concentrations needed to induce proliferation. Periodic pulses with BA in the liquid overlay has shown promise in overcoming apical dominance in proliferating cultures and allowing more axillary shoots to reach lengths suitable for in vitro rooting. With weekly transfers to new medium, most cultures did not show growth of any endophytic bacteria and appeared contamination free for several months or more. One explant from 'Sparrow' was maintained for more than a year before visible white halos formed in the agar solidified medium along the tissue margins.

Figure 2.—Proliferating mass of axillary shoots on 'Sparrow' initiated as an epicormic sprout from a branch segment cut from a 30-year-old tree.

DISCUSSION AND FUTURE RESEARCH DIRECTION

Cassells (1991) suggested endophytic microorganisms eventually adapt to the in vitro environment by utilizing the nutrients that leak from the tissues of the explant. This may explain the occurance of "white halos" observed around established black walnut explants in our experiments. Both gram-positive (*Agrobacterium*, *Bacillus*, and *Corynebacterium* spp.) and gram-negative (*Pseudomonas* spp.) bacteria have been reported as endophytic to certain plants (Meynier and Arnould 1989, Cassells 1991). Although most antibiotics are phytotoxic at concentrations needed to achieve bacteriostatic effects, other antibiotics such as rifampicin and imipenem are effective on many bacteria showing little toxicity to most plant cultures (Kniefel and Leonhardt 1992). Preliminary experiments, however, suggest rifampicin is toxic to proliferating cultures of black walnut at concentrations that will limit growth of endophytic bacteria. Solution to endophytic bacterial contamination of walnut shoots may require identification of the bacteria to facilitate future testing for antibiotic sensitivity of bacteria and walnut explants. As it has been found with other plants, combinations of antibiotics may be more effective than any single antibiotic (Young *et al.* 1984, Kniefal and Leonhardt 1992).

Of all the *Juglans* spp., Persian and black walnut are considered to the most difficult to root (Rodriguez *et al.* 1989). Most researchers have reported little success with in vitro or ex vitro rooting of black walnut cuttings or microshoots (Somers *et al.* 1982, Stefan 1989, Coggeshall and Beineke 1996). A few studies have reported on the successful rooting of black walnut cuttings (Farmer and Hall 1973, Shreve 1974, Carpenter 1975, Stefan 1989). Likewise, several researchers have shown that juvenile black walnut microshoots can be rooted. Caruso (1983) reported in vitro rooting on 5 of 10 shoots cut from embryos germinated in vitro. Seedlings were grown for 9 weeks on medium containing a conjugated auxin (indoleacetyl-phenylalanine) before terminal shoots were harvested and placed on half strength MS supplemented with 0.2 µm IBA.

Heile-Sudholdt *et al.* (1986) reported in vitro rooting on 4 of 13 axillary shoots using a 15-second quick dip in 10 mM K^+-IBA dissolved in 50% ethanol before inserting in sterile vermiculite moistened with distilled water. More than 80% rooting was achieved in one replication (4 of 5 shoots) and 0% rooting in two other replications using the same methods. Long *et al.* (1995) achieved 40% rooting of microshoots produced by somatic organogenesis on immature cotyledonary tissues. They pretreated microshoots for 1 week on DKW medium with half the normal nitrates, 50 g/L sucrose, and 1 mM IBA. Shoots were quick dipped for 10 seconds in 2.5 mM IBA and 1.25 mM NAA in 1% dimethyl formamide and 3.9% ethanol (1:20 dilution of Wood's Rooting Compound® in water) before inserting in sterile vermiculite moistened with LP medium.

The variability in rooting success suggests significant research effort is still needed to learn how to precondition plant cultures so that microshoots consistently respond to rooting treatments. Past rooting studies with black walnut have used talc, ethanol, or dimethyl formamide as the auxin carrier. Chong *et al.* (1992) showed an interaction between the auxin concentration and the auxin carrier needed to root hardwood cuttings with propylene glycol being more effective than either talc or ethanol. Likewise, the in vitro rooting substrate has been shown to affect root initiation and elongation of walnut hybrids (Jay-Allemand *et al.* 1992). Additional research is needed with walnut microshoots to evaluate use of auxin pulses with IBA and/or NAA to initiate in vitro rooting. Auxin pulses have been successfully used on other hardwoods (Navarrete *et al.* 1989). Preliminary results suggest that genotype is also likely to influence root initiation and in vitro root growth. Genotypic influences have been found for in vitro rooting of both white ash and white oak (Van Sambeek 1988, Preece *et al.* 1991).

Because in vitro techniques may offer the best chance for rooting black walnut microshoots, rooted plantlets will need to go through acclimatization from the in vitro environment to greenhouse conditions before field planting. During acclimatization, plantlets need to make the transition from a high humidity condition to a state capable of normal photosynthesis and transpiration under variable humidity (Preece and Sutter 1991). In our studies, it has taken 2 years to produce container-grown walnut plantlets large enough for field planting. During the first year in the greenhouse, plantlets developed a large root system with little shoot growth. During the second year under greenhouse conditions, plantlets developed an extensive root system with shoot growth similar to that of germinating nuts. It is unclear if greenhouse treatments can be found that will stimulate both shoot and root development during the first growing season.

Container-grown black walnut plantlets obtained through in vitro culture have shown normal tree growth. The first three micropropagated black walnut trees (FSL#1, FSL#2, and FSL#3) show strong apical dominance with above average lateral branching (Fig. 3). The increased branching is thought to be a function of selection for

Figure 3.—The first three black walnut trees (FSL#1, FSL#2, and FSL#3, left to right) produced by microculture 8 years after planting outside the USDA Forestry Sciences Laboratory on the Southern Illinois University campus.

axillary shoot proliferation during in vitro culture. These three trees began to flower and produce nuts 6 to 10 years after planting as 2-year-old container-grown plants in 1986 in front of the USDA Forestry Science Laboratory on the Southern Illinois University campus.

In conclusion, we have made significant progress in the last 15 years toward successful micropropagation of elite black walnut trees. Black walnut explants from nuts, seedlings, transitional and adult trees can now be routinely established in vitro with subsequent axillary shoot proliferation on several media supplemented with TDZ. Future research is needed to confirm these results and address problems associated with endophytic bacterial contamination, unpredictable in vitro rooting, and slow acclimatization of plantlets for production of genetically improved planting stock from adult black walnut.

ACKNOWLEDGMENTS

The authors would like to thank Walter F. Beineke, Archie Sparks, and the Nebraska Northern Nuts Growers for furnishing scionwood; Corina Wernet, Jinghua Zuo, Melissa Casteel, and Dave Close for assisting with grafting; and F. Danny McBride, Ron Meso, Aletha Kahle and Roger Campos for maintaining plant materials in the greenhouse.

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RELATING ANATOMY AND PHYSIOLOGY OF GERMINATED *JUGLANS NIGRA* L. SEEDS

J.A. Vozzo, M. Marko, R. Patel, and A. Terrell[1]

ABSTRACT.—The relatively large size of walnuts allow the imaging of cotyledons and embryonic axis, showing interactions of anatomy and physiology using current biotechnologies. A particular x-ray procedure (computerized tomography, CT) images individual sections of a walnut, allowing computerized reconstruction to present a 3-dimensional viewing. This 3-D image can be turned on either of its three axes for complete morphological review including internal measurements. The morphology of the walnut using CT is compared with its function by additional imaging with magnetic resonance imaging (MRI). MRI can locate, identify, and separate water molecules from fat molecules. Its advantage is that the MRI images are then compared with CT images which now relate form with function of each integral walnut entity, i.e., pericarp, cotyledon, and embryo. The entire process is nondestructive.

INTRODUCTION

Black walnuts (*Juglans nigra* L.) have relatively large seeds (25-30 mm) requiring stratification to germinate. This stratification process is usually followed by labor intensive preparations to cull germinated seeds with good seedling properties from ungerminated seeds and poorly developing seedlings. This care results in increasing the per seedling cost of handling and production. Any understanding of germination/seedling biology will contribute towards decreasing production costs. Quality control of viable seeds can be determined using new biotechnologies.

Conventional radiography presents one means of determining nondestructive quality testing for tree seeds (Vozzo 1988). It represents, or images, the density of biological tissue which is compared with both absolute density at one end of the scale and no density at the other end. The 256 shades of gray visible in the density range represent the biological and physical qualities within the seed. For example, a healthy plant tissue fully hydrated will be very dense (bright gray) while a dead, dry tissue will be much less dense (dark gray to black). Radiography, or x rays, provides interpretive value to understanding anatomy and morphology. A specialized x-ray technique, computerized tomography (CT), allows single-plane images of the seed at every 0.5 mm. This results in a flat-plane image showing all density structures as they would appear if hand sliced at that level. All the serial sections can be combined by computer to reconstruct a 3-dimensional model. This procedure is also nondestructive.

However, other factors are equally significant to understand and predict seed viability which may not be relative to x-ray imaging. Seed physiological properties, such as a dormancy (Vozzo and Young 1975), embryo challenge (Vozzo and Song 1989), and incomplete embryo development (Vozzo 1973) provide no absolute visible images but are strongly related. Magnetic resonance imaging (MRI) is also nondestructive to tree seeds. It is an imaging technique to identify and localize protons (the hydrogen nuclei) bound to bulk water and long-chain fatty acids. As both these metabolites are physiologically active

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during seed storage stratification, and germination, MRI has the value of imaging relative physiology. By comparing anatomy (x-ray images) and physiology (MRI), we can relate form and function as they interplay during prescribed seed treatments.

Pecan [*Carya illinoensis* (Wangenh.) K. Koch] seeds have been reported by Halloin *et al.* (1993) for their lipid distributions using MRI. *Vozzo et al.* (in press) relate the viability of black walnut seeds with water and lipid patterns determined by nuclear magnetic resonance (NMR) spectroscopy and MRI. Also, other agricultural seeds have been shown to image favorably using MRI (Foucat *et al.* 1993).

This presentation gives examples of the practical value of radiography and MRI to determine seed viability for storing, shipping, and germinating.

MATERIALS AND METHODS

Juglans nigra L. seed is large (30 mm long) with clearly defined cotyledons, embryo axis, and seedcoat. Seeds were collected in Starkville, MS (east central MS in the southeastern USA). After husk removal, fresh seeds were briefly stored dry at 4°C until analyses. Dry seeds were radiographed at 30 kVp, 3 mA, 180 sec at 65 cm on Kodak Industrex Type M film and developed manually. Each seed was individually identified for later CT and MRI analyses, as well as for germination determination. Seeds were imbibed 24 h in water, subjected to CT and MRI then pretreated for germination tests by stratifying for 90 days at 4°C inside moistened, black plastic bags. Seeds then were reimaged for CT and MRI and were germinated on moistened Kimpack in germination boxes with alternating 20° and 30°C regimes with 8 h of light at 30°C and 16 h dark at 30° (Brinkman 1974).

RESULTS AND DISCUSSION

Seeds examined with conventional radiography were easily divided into two groups based upon density of the radiographs: those that were empty (no well developed embryos), and those that contained well developed embryos. Initial CT and MRI experiments showed that seeds that appeared empty on radiographs also appeared empty in CT and MRI images. Seeds that appeared empty consistently failed to germinate following stratification, whereas some, but not all, of those with embryos germinated following stratification. All subsequent CT and MRI experiments were done on seeds that appeared in radiographs to contain well developed embryos. The relationship between anatomy (CT) and physiology (MRI) shows definite interactions relating specimen density to proton distribution.

Serial reconstructions from computer generated 3-dimensional images illustrate localization and densities of major seed structures: seedcoat, cotyledons, and embryos. False coloring assigned by spectral energy distribution ranges allow separation of shades of gray otherwise not obvious. Comparing empty, full nongerminated, and full germinated seeds, there is distinction by the amount and localization of false-color red. Wavelength energy of false-color red represents minimal viability to affect germination as densitometrically assigned levels of gray from CT radiographs. Empty seeds have minute or no red energies, while full nongerminated seeds show sparse and poorly localized or diffused red energies. The full germinated seeds are readily distinguished by their relative abundance of false-color red. Each seed representative is reconstructed and projected in 3-dimensional presentations of their X, Y, and Z axes during an 8-minute video.

In order to define the densities represented by red spectral wavelengths, magnetic resonance images show mobile proton distributions of hydrogen nuclei (H^+). Comparing density patterns from CT with the mobile proton distribution of MRI, the false-color density red pattern is translated to bulk water and long-chain lipid localization. Initially, MRI was a composite of both water and lipid protons. Later however, we were able to separate the two entities by altering the relaxation constants which separate water and lipid echo times. The resulting image verified that lipid protons were primarily responsible for image intensity.

Images acquired following stratification of seeds were more intense than those acquired before stratification. Intensification was due to increased water uptake during the stratification process. The water increase is interesting as it reflects both the amount and the distribution

internally. This water binding as a result of stratification was described by Faust *et al.* (1991).

Tissue densities are routinely imaged with conventional radiographic procedures and provide substantial interpretations regarding health and structure. As quality control techniques, they are limited to gross observations to distinguish full from empty, insect infested, and mechanically damaged seeds. CT provides single-plane-imaging which allows interpretations unimpaired by multiple strata of small but densely structured tissue. Hydration affects interpretation as water is a naturally occurring radiopaque contrast agent. However, water is also integral to the germination process as well as highly significant regarding seed storage. MRI gives an advantage in interpreting water movement internally. Any biological entity capable of undergoing MRI imaging is nondestructively observed as water moves within it. The correlations described here using walnut seeds are valid for detecting and localizing water and long chain lipids in other specimens as well. Germination data showed that all embryos lacking sufficient amount and distribution of lipid (as indicated by images before stratification) failed to germinate.

In the walnut industry for example, this technique can identify the amount and distribution of oil deposits (long-chain fatty acids) within different sources of seeds. In turn, this enables a selection for various grades/qualities of food-producing walnut meat designed at marketing and sales.

Quality control can be implemented by quantifying the state and status of internal water. Specifically, CT and/or MRI can provide beneficial procedures used to determine germination potential in walnut seeds. CT not only clearly provides density gradients related to seed viability, but also offers spatial fiduciaries to accurately (within 0.25 mm) measure internal structures. We imaged 48 walnuts at one time on standard 14 X 17 in. radiographic film. For MRI, we imaged nine walnuts at one exposure, however this can be expanded to image more seeds by using an instrument commonly found in large hospitals where MRI bores typically have inside diameters up to 40 cm. Neither CT nor MRI are sample destructive, meaning all seeds may be used for their originally intended purpose after imaging. Both techniques are highly useful with practical applications in quality control.

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DIRECT SEEDING AND SEEDLING PRODUCTION IN NURSERY BEDS

Terry L. Robison, William G. Yoder, and Greg Hoss[1]

ABSTRACT.—Studies and anecdotal evidence on direct seeding walnut show that success is most dependent on adequate germination and avoidance of rodent problems. This paper suggests strategies that growers should explore to increase success rates. Nursery programs, which in effect are large direct seeding projects, show that intensive management yields good seedlings. Combining knowledge from nursery and field applications provided ideas and recommendations for future direct seeding projects. Intensive site preparation, stratified or pre-germinated seed, weed control, and possibly nitrogen fertilization could lead to more successful plantings.

INTRODUCTION

A literature search turned up few studies on the direct seeding of Eastern black walnut (*Juglans nigra* L.). Many walnut growers have tried direct seeding, but consistent success seems elusive. To develop recommendations for direct seeding, we first present results from walnut direct seeding experiments and case studies to see what we can learn from past attempts. Second, we explain how seedlings are produced in bareroot nurseries because lessons learned may be valuable when trying to establish plantations from seed. Finally, we synthesize the nursery and direct seeding information to present a guide for future walnut direct seeding projects.

DIRECT SEEDING

Cost savings and the development of a natural root system are often given as advantages of direct seeding over planted seedlings. It is also a project that most landowners can do on their own. However, application of the practice has met with varied success. Survival and growth can be low, and replanting can quickly add costs in the form of sweat equity. What works with direct seeding? Where can possible improvements be made? To answer these questions, we will look at some experimental and field applications of direct seeding.

Dierauf and Garner (1984) installed a series of studies on direct seeding of black walnut. In one, fall and spring sown walnuts were compared with spring planted seedlings at four locations in Virginia. They sowed nine walnuts at each spot, with 60 spots each for fall sown, spring sown and planted seedlings at each site. A mixture of simazine and paraquat was sprayed around the planting spots and the seedlings avoiding the area directly above the seed. After 7 years, height growth was virtually equal among the three treatments, in spite of the planted seedlings averaging a height loss over the first 2 years. Seedlings averaged 10 feet in height compared with 9.4 and 9.5 feet for fall and spring sown walnuts (Fig. 1). However, the results showed that spring sown stratified nuts produced better stocking than fall sown at three of four planting locations (average 90% vs. 76%). Spring planted seedlings produced better stocking than either seeding method averaging 98% survival across sites (Table 1). They define stocking as one or more seedlings per planting spot.

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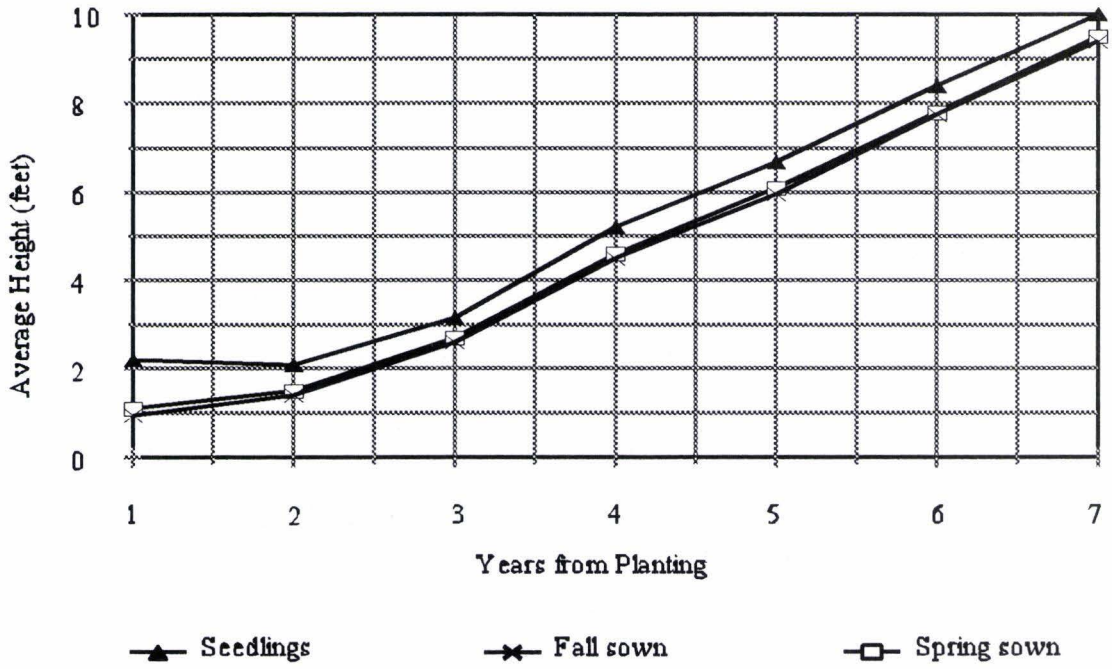

Figure 1.—Average height of fall and spring grown walnuts versus planted seedlings (Dierauf and Garner 1984).

In a companion study reported in the same article, Dierauf and Garner examined how seed size and planting depth affected germination and 5-year height on three different planting sites. Nuts smaller than 1 in. in diameter consistently produced fewer seedlings (i.e., less germination) than larger nuts. Stocking success and height growth varied greatly by planting site with no apparent relationship between seed size and subsequent 5-year height. Multiple seedlings at a seeded spot did not affect the dominant seedling's growth. Sowing depths of 3, 5, and 7 in. produced inconsistent results, with only slight differences among the three planting depths. They could not assess the effect of planting depth on squirrel pilferage because pilferage was nonexistent in these studies. They suggested that direct seeding would be easier if seed was sown in furrows (i.e., rows) rather than spots. Rows would also aid subsequent cultural work.

Table 1.—Fall and spring direct seeding stocking compared with planted seeding survival after 1 year (adapted from Dierauf and Garner 1984)

	Spots stocked (%) and average number per spot out of nine nuts planted				
	Fall		Spring		Planted
Tract	%	Number	%	Number	seedling survival
Bowman	95	2.5	93	2.8	100
Currin	75	1.7	95	2.5	98
Smith	73	1.4	85	2.8	95
White Hall	63	1.9	87	2.4	98
Means	76	1.9	90	2.6	98

Squirrels, chipmunks, and other rodents create predation problems for direct seeding projects (e.g., Burke and Williams 1973). Experience shows that repellents do not work (Lamont and Clark 1959, Williams *et al.* 1977), although direct seeded walnuts covered with cow manure has yielded mixed success (Williams and Funk 1979). Squirrels seem attracted to germinating nuts (MacDaniels 1984) or the combination of scent and soil disturbance caused by planting (Stapanian and Smith 1978). They can find rows planted to walnuts, and then systematically steal them. Removing the hull may help deter rodents (Nielsen 1973), but research suggests that only intensive cleaning, including repeated washing and wire brushing to remove all hull debris, makes the nuts safe (Phares *et al.* 1974). Usually, predators are more of a problem near field/woods borders because they are reluctant to stray too far from cover. Work with oak direct seeding suggests that large-field plantings with proportionately less edge would be more successful than small-field plantings (Johnson and Krinard 1987). The season of planting may also contribute to the problem. In one study, late spring planting resulted in the least predation followed by early spring and then fall planting (Lamont and Clark 1959). Once established, seedlings of any origin are susceptible to damage from deer, insects, and other pests.

Fertilization studies on direct seeded plantings are lacking. Pallardy and Parker (1989) state that fertilization effects will vary depending on site characteristics. On nutrient poor soils where fertilization would likely be beneficial, other site factors such as water may limit or negate the effect of added nutrients. Studies on planted seedlings show that fertilization should be delayed until after establishment (i.e., 3 years) because of cost and weed stimulation problems (Schlesinger and Funk 1977). However, where fertilizers have stimulated growth in young plantings, the added nutrients, especially nitrogen, may be replacing those used by competing weeds (Pope *et al.* 1982, von Althen 1985).

Weed control benefits direct seeded plantings as it does those established with seedlings (e.g., von Althen 1977, 1989). In one study, glyphosate for at least 2 years after establishment helped growth of direct seeded walnut; however, simazine (80W at 5 pounds per acre) applied at the time of sowing reduced establishment success (Philo *et al.* 1983). Simazine, a pre-emergent herbicide, may have stopped early growth of the walnut seedlings at this rate. No herbicides are currently labeled for use at the time nuts are planted.

Several private landowners and Missouri Department of Conservation District Foresters provided anecdotal evidence on their experiences with direct seeding. Overall, they favored seedlings over direct seeding, with rodent problems and inconsistent germination being the main reasons for dissatisfaction. Where squirrels or other rodents were plentiful, direct seeding was unsuccessful. Tree shelters, repellents, screens, and deep planting did not prevent pilferage. Cases of complete failure were prominent. One successful use of direct seeding was to supplement established plantings to fill holes where seedlings had died. Successful direct seeding projects needed up to 3 years of replanting to obtain adequate stocking. One exception was a landowner who created raised beds (20 in. wide) in August, allowed them to settle, then planted with freshly collected walnuts in the fall (Ed Masters, personal communication). He attributes good survival and growth to good, local seed sources and a lack of squirrels.

One other example is worth noting. Walt Beineke (personnel communication) has been experimenting with a method that is yielding up to 70% stocking while planting only one walnut per planting spot. Site preparation consists of plowed and disked fields or fields treated with glyphosate to kill all vegetation. He then uses a post-hole digger to create a 3-4 in. deep holes, inserts a 2-ft tube-type tree shelter into the hole, and stakes the shelter in place. He drops one pre-germinated walnut into the shelter followed by several handfuls of soil. A bird net supplied with the shelter is used to prevent rodents and birds from entering the top of the shelter. The seeding is done in mid- to late May to avoid any chance of frost. Nuts failing to develop are lost to rot and depredation. In spite of these results, Walt still questions the use of direct seeding over planted seedlings.

NURSERY PRODUCTION

Seedlings grown at nurseries are produced in protected and nourishing environments that can be quite different from the harsh realities of the field. However, the cultural practices used may

provide useful guidelines for successfully direct seeding walnut in the field. Procedures at the Missouri Department of Conservation's George O. White State Forest Nursery are typical of those used at many other state and private nurseries throughout the range of black walnut. At these nurseries, 1-0 seedlings are produced using intensive, agricultural management schedules. Mugford (1984) explains in detail the process for growing tree seedlings including black walnut. Growing 1-year-old seedlings actually takes 2 years of work. In late spring of year one, walnut nursery beds are fertilized to reach available nutrient content for nitrogen, phosphorus and potash of 45, 150, and 275 pounds per acre, respectively. Soil acidity is adjusted to a pH near 6.2 (6.0 to 6.5) with lime or sulphur. Soil testing reveals other micro- or macronutrient deficiencies to correct. Every third year, hybrid sorghum-sudan grass is sown at a rate of 30 pounds per acre with 500 pounds of fertilizer (1-3-5). The green manure crop is incorporated in mid-July, followed 60 days later by soil fumigation (methyl-bromide) for weed and disease control. No matter whether a cover crop is sown, walnuts are always sown into freshly fumigated beds.

Seeds sown at the White Nursery come from various sources. Walnuts purchased locally come mostly from within a 50-mile radius of Licking. Progeny tests placed throughout the state show that these local seedlings rank in the top 50% for growth characteristics compared with other sources. This supports the long held recommendation that walnut seed sources can be moved up to 200 miles north of their origin (Bey 1979). A northern buying station is set up in St. Joseph to provide a distinct northern geographic source for distribution. Recently, seed orchard seed has become available, and over time, genetically improved seedlings will be distributed from the nursery. Similar tree improvement programs are active throughout the black walnut range (Robison and Overton 1989).

As walnuts are received in the fall, nursery personnel sow them uncleaned into raised, 4 ft wide beds with five rows per bed. The beds are mulched with 2 to 3 in. of aged sawdust held in place with hydromulch. Bed density after sowing is such that four to six plantable seedlings grow per square foot. For the most part, overwintering in the seed bed satisfies the stratification requirement for walnuts (Williams 1982). Germination at our nursery averages 40-60%. We have observed second year germination in fallow beds that can add 20-30%. In Indiana, approximately 10 to 12 gallons of hulled walnuts are planted per 100 square feet of bed space. This amount yields 500-600 shippable seedlings (Wichman *et al.* 1990).

Walnuts begin to germinate in late April. Two to three times during the growing season, beds are top dressed with granular ammonium nitrate (33-0-0). Fifty pounds per acre are normally added in late May or early June, with a second treatment of 50 pounds in late June or early July. A third application is sometimes applied in late July or early August; however, nitrogen is not applied after mid-August to avoid problems with the hardening process. We have experimented with foliar applications of liquid urea (45-0-0) at 8 ounces per acre biweekly with good success. One year, in an experiment concerning the control of anthracnose, 800 pounds per acre ammonium nitrate was applied to several treatment beds in the spring before seedling emergence. We grew walnut seedlings 4 to 6 ft tall (Chris Luley 1988, Missouri Department of Conservation internal report). The study confirmed that walnut seedlings can respond to high nitrogen fertilization without burning; however, these seedlings did not harden properly in the fall.

Other cultural treatments include irrigation, undercutting and pest control. Seedlings are irrigated to achieve 1 in. of rainfall equivalent per week. We use undercutting to arrest height growth and stimulate formation of lateral roots. Seedlings with 12 or more permanent, first-order lateral roots have increased survival and growth (Schultz 1994). Insect problems are few, but root rots of various causal agents have led to crop losses both in the field and cold storage of up to 50%. Fungicides are occasionally used to control anthracnose (Wichman *et al.* 1990).

Herbicides are not routinely used in walnut culture at our nursery. Fumigation before sowing keeps weed growth minimal before germinating walnut seedlings occupy the beds. Our walnut beds were part of a screening study to select preemergent herbicides for use on several species (Garrett *et al.* 1988). Oryzalin at 4 pounds per acre applied to bare soil prior to fall mulching gave the best weed control and seedling quality at the lowest cost. Oxyfluorfen at 2

pounds per acre applied in the spring prior to emergence performed similarly. In another nursery study, oxyfluorfen at 0.1 to 0.25 pounds per acre also was safe on walnut seed beds (Grauke and Gouin 1984). In unreported studies at our nursery, simazine and pendimethalin also look promising.

Some nurseries remove the hulls and float seed prior to sowing (Wichman *et al.* 1990). Hulling's biggest advantage is the resulting uniform rate of germination. However, germination rate results from float tests can be misleading if not performed within 3 days of hulling fresh walnuts (Williams 1982). Both the Indiana and Missouri state nurseries have experimented with planting stratified seed to increase germination uniformity. Stratification in pits outdoors or under refrigeration has been used to prepare nuts for spring planting. The length of stratification is important, with at least 60 days needed to allow germination. Stratification for 120 days yields the most prompt germination of walnut seed (Williams 1971, 1982; von Althen 1971).

We routinely use stratified nuts to produce seedlings for progeny testing. As nuts are collected, they are hulled, soaked for 12 hours, and drained. The nuts are then placed in 4 mil poly bags, sealed, and placed in a cold storage room for 90 to 120 days prior to sowing. Condensation inside the bags shows proper moisture levels. If no condensate is apparent, water is added to the bag. If water pools in the bottom of the bag, then we drain it.

As with direct seeding, the nursery beds suffers from squirrel depredation. However, the percentage of nuts lost to squirrels is low because of the overwhelming numbers of walnuts in the beds. We take no actions to prevent squirrels from having their share. Crows, blue jays, and blackbirds, however, can cause serious losses of germinating seedlings. Control actions are frequently taken against these pests including pie pans and streamers on posts to shotguns.

Once the seedlings are through their first summer of growth, the management of a direct seeding project switches from nursery-type to plantation management. From this point on, weed control becomes the number one task. For your general information, however, seedlings at a nursery are dug from beds after they reach dormancy, usually early December in southern Missouri. They reach dormancy when root elongation has ceased or 2 to 4 weeks after leaf drop. Plants are then moved to humid, cold storage at 32° to 35°F until they are graded and shipped.

LESSONS LEARNED

We can learn key lessons from nursery seedling production to increase direct seeding success. First, site preparation is critical to the successful production of seedlings. Tilling and cover crop management help to control weeds and improve soil tilth and organic matter content. Subsequent weed control is not necessary in nursery beds because the seedlings grow quickly and totally occupy the site before weeds can become established. However, weed control in the field is critical for the successful establishment of seedlings.

Direct seeding projects should begin with intensive site preparation to control weeds and prepare a seed bed. Options range from spot preparation by scalping or spot herbicide application, to broadcast herbicides to full plowing and disking. Many studies show the benefits of complete weed control through at least the first 3 years of establishment (von Althen 1977, 1989; Philo *et al.* 1983; Schlesinger and Van Sambeek 1986). It is our feeling that the more site preparation and subsequent weed control that you do, the better off your germinating seedlings will do.

Second, nutrient management helps first year growth of walnut seedlings in nursery beds. Nursery beds are similar to agronomic crop fields where nutrients are depleted with each removal of a crop. If a direct seeding project is planned for an abandoned crop field, there is a good chance that some nutrients may be lacking. A soil test the year before planting would be wise, and it would allow time to raise nutrient levels up to specifications. Fertilization studies on black walnut suggest that on less than optimal sites, the addition of nitrogen can increase growth (Braun and Byrnes 1982, von Althen 1985, Ponder 1984). Also, the addition of above optimum amounts of nitrogen have stimulated significant growth responses in our nursery. Experimentation in field plantings is warranted. However, fertilization adds to the costs of management. Unless you are prepared to battle the weeds that will also respond to the fertilizer

treatments, then delaying fertilization until after the trees have captured the site might be best (Schlesinger and Funk 1977, Pallardy and Parker 1985). Thus, for field planting, the best advice is to begin with a high quality walnut site (Ponder 1982, 1988). Choosing anything less than optimal conditions will cause losses in walnut growth over the rotation of the plantation.

Combining intensive weed control with fertilization, as is done in a nursery, may help establishment even further. One study (Pope *et al.* 1982) looked at fertilization combined with weed control in a 12-year-old plantation. Neither treatment affected height, diameter nor volume growth without the other. However, when combined, a distinct growth increase occurred. This study was limited to one application of fertilizer and 1 year of weed control. Continuous weed control combined with intermittent applications of fertilizer could stimulate growth no matter how we establish a plantation.

Third, choosing the correct seed source is important in achieving acceptable results. Tree improvement research shows that using seed sources 100 to 200 miles south of the area to be planted maximizes growth (Deneke *et al.* 1980) except in the most northern parts of the black walnut range (Bey 1979). Direct seeding lends itself to the use of recommended seed sources for your planting area.

Finally, rodents, particularly squirrels, are a big problem limiting success. Nursery and direct seeding experience give some hints on how to deal with squirrel pilferage that suggest further exploration. Providing an abundance of walnuts or acorns in rows close to squirrel habitat may help satiate their hunger and reduce losses further from field edges. These should be fresh out of stratification or disked lightly into the soil to prevent drying. Nuts left on top of the ground and allowed to dry do not seem to attract squirrels (John Slusher, University of Missouri-Columbia). Late spring planting with optimally stratified (minimum 120 days) or pre-germinated seed should provide quick germination and seedling growth. By delaying planting, other food sources will be available for the squirrels.

CONCLUSIONS

Cost differences between direct seeding and planting seedlings are not likely if the planting is done correctly. We believe the lack of success with walnut direct seeding is caused in part by providing less than optimal conditions for seed germination and growth.

General procedures for direct seeding walnut are outlined in the North Central Forest Experiment Station publication "Walnut Notes" (Burde 1988). This publication is an excellent reference for walnut growers. Below we have listed what may be an optimal approach to direct seeding. Some procedures are speculative, but are supported by indirect evidence. Overall, planting seedlings is the preferred method for establishing walnut plantations. However, there is still an inherent "feel" about beginning a plantation from seed so that trees become established with no disturbance.

1. Begin **site preparation** in the fall or even in the spring before seeding walnut. For optimum results, plow and disk the entire planting site if soil erosion is not a problem. Otherwise, plow and disk strips to be planted. Cover crops can help build soil organic matter and reduce weed competition. Avoid cover crops such as fescue, which has allelopathic effects on walnut, or others that compete too vigorously for water and nutrients (Van Sambeek 1988).

2. Get a **soil test** to detect if any nutrients are limiting. Bring nutrient levels up to levels recommended for corn, but be prepared to battle the weeds.

3. Obtain **seed** from local or slightly southern sources. **Late spring** planting with seed stratified for 120 days, or stratified then pregerminated, may provide the best protection from rodents. Float the nuts immediately after hulling to increase germination success if pre-germinated seeds are not used. Hulling and stratification are not necessary if the nuts will be fall planted.

4. Seed should be sown one to 2 in. into the soil by hand or with a planting machine. Planting in rows simplifies later maintenance such as herbicide application, mowing and thinning. Pre-emergent herbicide application to bare soil at this time would help decrease weed competition and rodent habitat. However, no herbicides are currently labeled directly for use with direct seeding. Glyphosate can be used to control established weeds.

5. If squirrels are a potential problem, place copious amounts of fresh acorns, walnuts and other food sources between their habitat and your planting. Disk the nuts into the ground. Allow hunting on your acreage as another control measure.

6. Addition of nitrogen **fertilizer** about 1 month after germination may give the new seedlings a growth boost to quickly establish the site, providing weed control is complete. Actual application rates and formulations need to be determined.

7. Completely **control weeds** for at least 3 years, and preferably longer.

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EVALUATING BLACK WALNUT PLANTING STOCK QUALITY

R. C. Schultz and J. R. Thompson[1]

ABSTRACT.—Bareroot forest nurseries in five midwestern states established a cooperative in 1987 to evaluate and improve hardwood seedling morphological characteristics, particularly seedling root systems. Species studied included red oak, white oak, and black walnut. Seedlings were grown at three densities (32, 64, and 96 seedlings m^{-2}) and half of the density plots were undercut. Seedlings were lifted, measured (height, diameter, and number of first-order lateral roots[FOLR]) and outplanted in their respective states. Annual measurements of survival, height, and diameter were made. Seedling size and number of FOLR decreased with increasing bed density. At a given density, undercutting produced seedlings with smaller shoots that had greater numbers of FOLR. After outplanting, percent survival, total height, total diameter, height increment, and diameter increment increased with increasing numbers of FOLR.

INTRODUCTION

Work with hardwood species in the southern and central United States has indicated that root system morphology can be a major determinant of seedling success (or failure) in the field (Kormanik 1986, Schultz and Thompson 1990). Survival and shoot growth after transplanting depend to a great extent on the seedling root system and the ability of the seedling to rapidly produce new roots (Farmer 1975, Sutton 1980, Burdett *et al.* 1983, Kormanik *et al.* 1988, Rietveld and Van Sambeek 1989, Barden and Bowersox 1989).

Especially for stock cultured in bareroot nurseries, the potential for new root production (root growth potential) can be related to the presence of an adequate system of relatively large (> 1 mm proximal to the taproot) permanent first-order lateral roots (FOLR) (Thompson 1991). FOLR that arise within the portion of the taproot that is lifted are generally able to survive the rigors of lifting, packing, storing, shipping, and planting procedures, and provide sites for initiation of new roots during the seedling establishment phase (Thompson and Schultz 1995). Periodic seedling excavations have indicated that these roots do persist after planting (e.g., Thompson 1991).

Forest nurseries in five states (Illinois, Indiana, Iowa, Missouri, and Ohio) established a cooperative in 1987 to improve cultural control of hardwood seedling morphology. Other states, including Wisconsin and Minnesota, have participated in some studies. Evaluation of bed-run 1+0 bareroot stock from several nurseries before studies were initiated indicated that 28 to 33% of black walnut seedlings had fewer than five FOLR (Schultz and Thompson 1990). The cooperative emphasized practices that might increase numbers of FOLR on seedling root systems. Control of seedbed density and use of undercutting were the initial treatments chosen for study. Subsequent studies also outlined in this paper examined genetic aspects of root morphology and response to undercutting, and effect of tree shelters on seedling growth and plantation establishment.

Although red oak (*Quercus rubra* L.), white oak (*Quercus alba* L.), and black walnut (*Juglans nigra* L.) seedlings were included in these studies, results for only black walnut seedlings are presented here.

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MATERIALS AND METHODS

Density plots were established in regularly planted beds of 1-0 mixed seedlots of black walnut stock in spring 1987 in the state nurseries of Illinois, Iowa, and Missouri by using a 0.3-m grid to achieve uniform density. Thinning was done where necessary by clipping one stem of closely spaced seedlings. Black walnut was thinned to densities of 32, 64, or 96 stems m^{-2}. Half of the density plots were undercut at a depth of 15-20 cm when the taproots were 6.0 to 13.0 mm in diameter at a depth of 15 cm (in late June or early July). Each density-undercutting combination was replicated in the nursery beds five to six times. Plots received fertilizer, weeding, and irrigation treatments customary at their respective nurseries. Seedlings were lifted during spring 1988; 40 seedlings were randomly selected for evaluation and field planting from each of the replications (for a total of 200 to 240 seedlings per treatment).

Seed for a study on genetic influences on walnut seedling root morphology was grown in plots by mother tree in Illinois, Iowa, Missouri, and Ohio nurseries during the 1988 season. All seedlings were grown at densities of 64 stems m^{-2} and were not undercut. Numbers of seedlings grown per parent tree varied from 35 to 90 according to availability of seed. Again, seedlings received fertilizer, weeding, and irrigation treatments customary at their respective nurseries.

Stock used in a plantation establishment study with tree shelters were grown in their respective nurseries during the 1990 season. These seedlings were sorted into six groups based on numbers of FOLR (0-6, 7-11, and 12+) on the lifted taproot, and whether undercut or not. Eight replications of 10 seedlings from the six groups were planted for each of two planting methods for a total of 960 seedlings.

For all three studies, seedlings were measured before planting to determine (1) height from the root collar to the base of the terminal bud, (2) diameter at approximately 1.3 cm above the root collar, and (3) the number of first order lateral roots >1mm, including a separate assessment of FOLR that resulted from undercutting (wound roots arising just above the point of undercutting).

Seedlings were outplanted (density/undercutting study planted in spring 1988, progeny tests planted in spring 1989) in their respective states as completely randomized individual tree plots, except for the plantation establishment study, which was planted in spring 1991 as a split-split plot design.

For the density/undercutting and genetic studies, seedlings were planted at a 1.2-m x 2.4-m spacing by using a two-person power auger with a 20-cm diameter bit. Planting sites were typically abandoned agricultural land (rowcrop or hay ground). Sites were maintained with combinations of chemical and mechanical weed control. In the plantation establishment study, half of the seedlings were planted using a power auger, and half were planted with a large hardwood planting machine. A 2.4-m x 3.0-m spacing was used, with graded trees placed in alternate rows. "Nurse" tree seedlings (green ash on the site reported on in this paper) were planted in rows between the graded trees. Four-foot, tan-colored "Tubex"™ tree shelters were installed on half of the graded seedlings at the time of planting.

Height and diameter were measured at the end of each growing season 1988 (1989 or 1991) through 1992, and then again in 1994. Data were analyzed and ANOVA done using the GLM procedure of SAS (SAS 1989).

RESULTS AND DISCUSSION

For brevity, only data from selected states involved in these studies will be presented in this paper. Results are presented for (1) density and undercutting treatment effects on FOLR (1988 study) in Illinois and Missouri; (2) seedling survival and growth related to FOLR (1988 study) in Missouri; (3) genetic influences on FOLR (1989 study) in Ohio; and (4) seedling establishment with tree shelters (1991 study) in Iowa.

NUMBER OF FOLR PER TREATMENT

Effects of bed density and undercutting on number of FOLR for black walnut grown in Illinois and Missouri are shown in Table 1. At a given density, seedlings that were undercut had greater numbers of FOLR. This was due to both

the development of wound roots at the end of the severed taproot (approximately 15 to 20 cm below the soil surface), and the thickening of existing lateral roots above the cut (Schultz and Thompson 1990). Field lifting procedures were used, typically severing seedling roots at 24 to 27 cm below the soil surface. Although root system morphology differed between undercut and not undercut seedlings, they were lifted using a blade at approximately the same depth. Seedlings grown at lower densities had more additional FOLR attributable to undercutting.

Mean number of FOLR for seedlings grown in Illinois ranged from 18 for undercut seedlings grown at 32 seedlings m^{-2} to 7 for those grown at 96 seedlings m^{-2} and not undercut (Table 1). Differences in number of FOLR due to both density and undercutting for the Illinois seedlings were significant at the 0.01 level.

Mean number of FOLR for seedlings grown in Missouri ranged from 16 for undercut seedlings grown at 32 seedlings m^{-2} to 8 for those grown at 96 seedlings m^{-2} and not undercut (Table 1). These differences among the Missouri seedlings were also significant at the 0.01 level. Increases in FOLR at a given density due to undercutting were significant at densities of 32 stems m^{-2} and 64 stems m^{-2}, but there was less difference in number of FOLR between undercut and not undercut seedlings grown at 96 stems m^{-2}.

The effects of density control and undercutting on numbers of FOLR show that there was an advantage in limiting nursery bed density, and if density was low enough undercutting substantially increased average numbers of FOLR. However, undercut seedlings were shorter and smaller in diameter at the time of outplanting than not undercut seedlings.

Lowering bed density increased the proportion of seedlings that had at least seven FOLR to 60% for not undercut seedlings and 80% for undercut seedlings. This was in contrast to data already mentioned for planting stock produced by most nurseries the previous year, probably because

Table 1.—Effects of nursery bed density and undercutting on number of FOLR for black walnut grown in Illinois and Missouri

State, Density/Undercutting treatments	Number FOLR		
	Lateral roots	Wound roots	Total
Illinois			
32 seedlings/m^2			
undercut	14	4	18a
not undercut	11	0	11c
64 seedlings/m^2			
undercut	11	3	14b
not undercut	8	0	8d
96 seedlings/m^2			
undercut	9	3	12c
not undercut	7	0	7d
Missouri			
32 seedlings/m^2			
undercut	12	4	16a
not undercut	14	0	14b
64 seedlings/m^2			
undercut	9	4	13c
not undercut	10	0	10d
96 seedlings/m^2			
undercut	6	3	9d
not undercut	8	0	8e

Means followed by the same letter are not significantly different at p=0.01

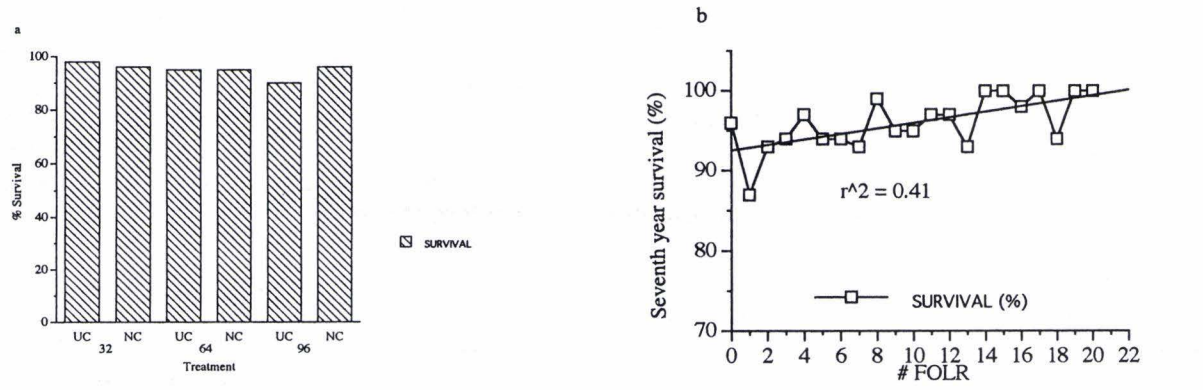

Figure 1.—Effects of (a) bed density, and (b) number of FOLR on 7-year survival rates for black walnut seedlings grown in Missouri. US = undercut, NC = not undercut, numbers indicate seedlings m^{-2}.

seedlings had previously been grown at densities even greater than the maximum densities used in this study. Based on these results bed densities of 32 to 64 seedlings m^{-2} are recommended for bareroot culture of 1+0 black walnut.

SEEDLING SURVIVAL AND GROWTH

The effects of nursery bed density, undercutting, and numbers of FOLR on 7-year survival for black walnut grown in Missouri are shown in Figure 1.

For Missouri black walnut, there was a slight difference in survival rates between the treatments, with 98% survival for seedlings grown at 32 seedlings m^{-2} (both undercut and not) down to 90% for undercut seedlings grown at 96 seedlings m^{-2} (Fig. 1a). Although regression analysis indicated increased survival with greater numbers of FOLR (Fig. 1b), the regression coefficient for the Missouri data was relatively low (r^2 = 0.41). Seventh-year survival vs. number of FOLR for black walnut seedlings planted in all cooperating states indicated uniformly good performance of seedlings with at least seven to nine FOLR (Schultz and Thompson 1990, 1996).

Average numbers of FOLR produced by seedlings in each of the treatment groups were adequate (threshold) numbers of roots for acceptable performance in the field. However, a greater proportion of the seedlings with four or fewer FOLR came from the higher density plots that were not undercut than from the lower density plots that were undercut.

The effects of density and undercutting on 7th-year height and diameter for Missouri black walnut are shown in Figure 2. Average seedling height ranged from 220 cm for not undercut seedlings grown at 32 stems m^{-2} to 193 cm for undercut seedlings that were grown at 96 stems m^{-2} (Fig. 2a). For the walnut, undercut seedlings grown at a given density were initially much shorter than not undercut seedlings (Schultz and Thompson 1990), and although they have grown more rapidly than those that were not undercut, on the average they remain slightly shorter. Seedling diameters ranged from an average of 37 mm for not undercut seedlings grown at 32 stems m^{-2} to 32 mm for undercut seedlings grown at 96 stems m^{-2} (Fig. 2b). The trend for seedlings grown at lower densities to be larger than those grown at higher densities continued, although size differences for the black walnut seedlings after 7 years in the field were only significant for seedlings grown at 32 stems m^{-2} and not undercut compared to all others.

Generally, the results of this work indicated that field performance in terms of survival, height growth, and diameter growth was related to seedling morphology, and that seedlings with adequate FOLR performed better than seedlings with few FOLR. Cultural practices that increased numbers of FOLR improved seedling performance after planting.

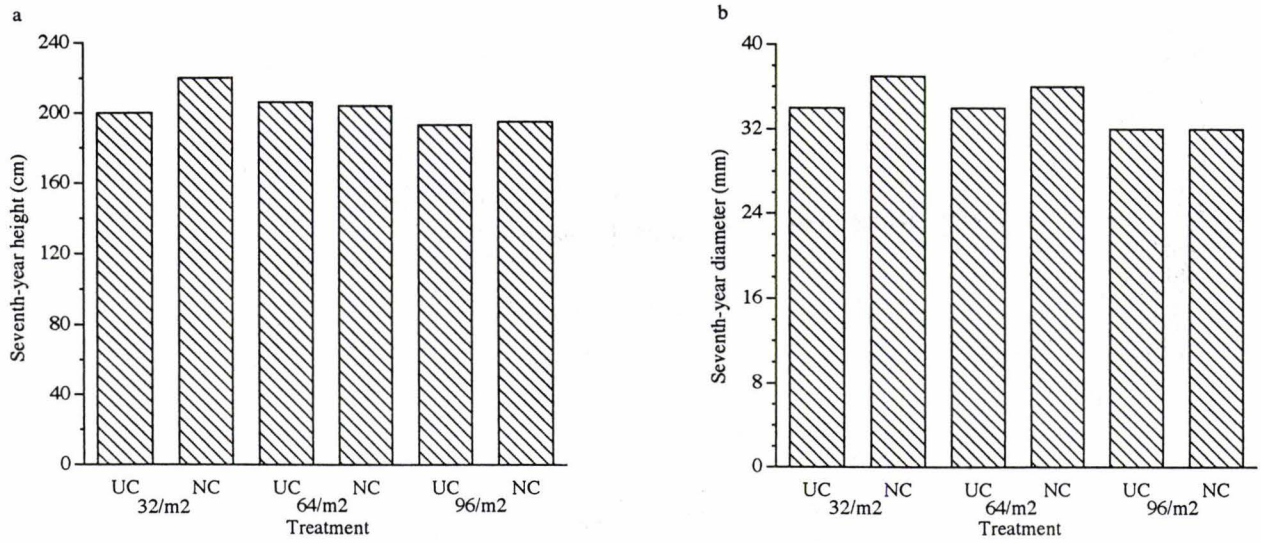

Figure 2.—Effects of density and undercutting on seventh-year (a) height and (b) diameter for black walnut seedlings grown in Missouri.

GENETIC INFLUENCES ON NUMBER OF FOLR

Average number of FOLR by parent tree, and 6th-year height and diameter for the Ohio black walnut selections outplanted in 1989 are shown in Figure 3. Mean numbers of FOLR were 10 or greater for all of the selections (Fig. 3a). These seedlings were grown at a controlled density of 64 stems m^{-2}, which may have enhanced expression of FOLR. Differences between average number of FOLR between families were significant at the .01 level. Based on work done with separate seedling samples from the same family populations, several morphological traits, including lateral root biomass (closely related to number of FOLR), had relatively high heritability (Feret 1990). These results suggest the possibility for genetic improvement of seedling root morphology through selection of specific seed sources, in addition to improvement from cultural treatments.

Although there were differences in height between families for seedlings outplanted in Ohio (Fig. 3b), after 6 years in the field few differences were statistically significant. This may have been due to relatively high average numbers of FOLR for all selections. Differences between average diameter for different families after 6 years were greater (Fig. 3c). Seedlings from parents T2, T4, T5, and T6 had higher average numbers of FOLR and performed well in terms of both height and diameter growth.

SEEDLING ESTABLISHMENT WITH TREE SHELTERS

Results after 4 years in the field for sheltered and unsheltered black walnut seedlings from different root grade groups that were hand-planted in Iowa are shown in Figure 4. Average survival rates ranged from 94% for seedlings with 0-6 FOLR grown without shelters to 100% for seedlings with 7 or more FOLR grown with or without shelters (Fig. 4a). Shelters enhanced survival of seedlings with fewer than 6 FOLR slightly.

Average height of the seedlings after 4 years ranged from 79 cm for not undercut seedlings with 6 or fewer FOLR without shelters to 173 cm for both undercut and not undercut seedlings with 12 or more FOLR that had shelters (Fig. 4b). Four years after planting, seedlings in tree shelters were nearly twice the height of seedlings that were not sheltered. Since sheltered seedlings were so much taller than their non-sheltered counterparts, statistical analyses of height for sheltered and unsheltered seedlings were performed separately. For both sheltered and unsheltered seedlings there were significant differences in average height after 4 years between root grade groups.

Average diameter of the seedlings ranged from 16 mm for not undercut seedlings with 6 or fewer FOLR that were not sheltered to 23 cm for not undercut seedlings with more than 12 FOLR that

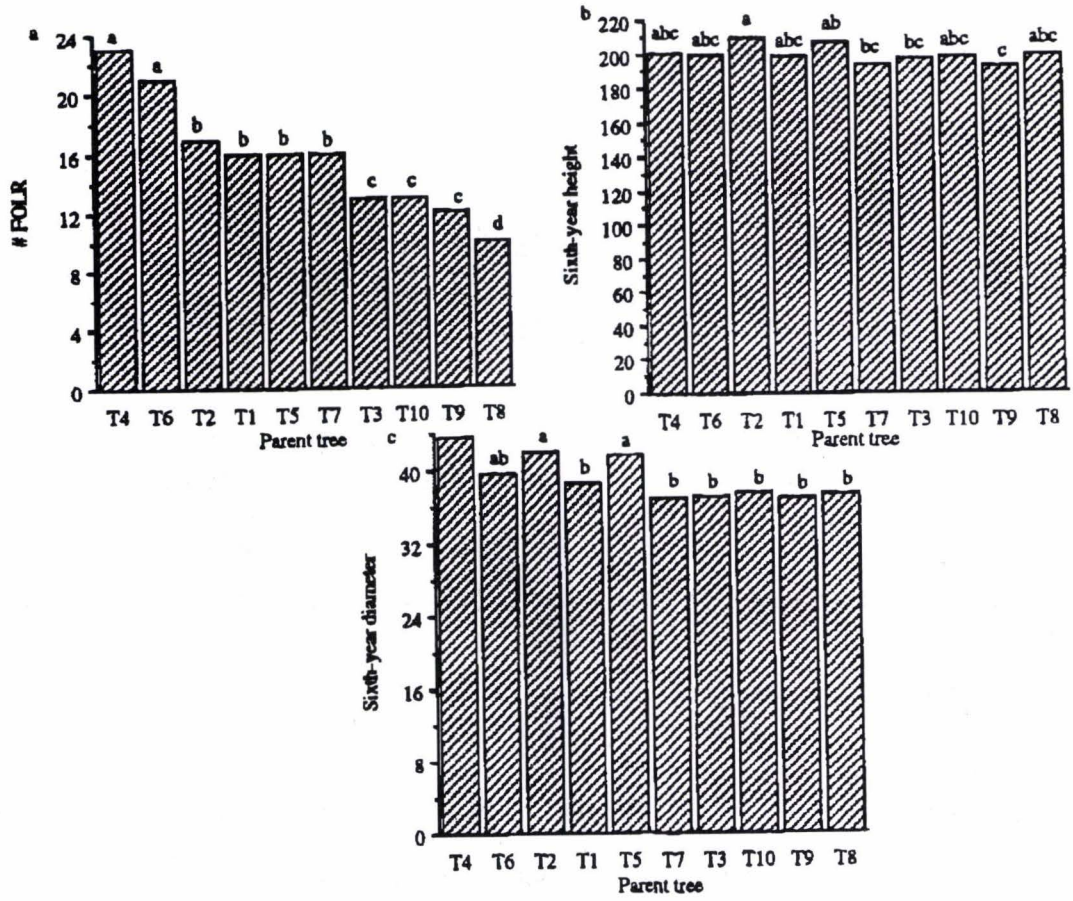

Figure 3.—Parent tree effects on (a) number of FOLR, (b) sixth-year height, and (c) sixth-year diameter for black walnut grown in Ohio. Columns with the same letter are not significantly different at the p = 0.01 level.

were sheltered (Fig. 4b). Even though the sheltered seedlings were dramatically taller than the unsheltered, differences in diameter between them were insignificant. Thus, the height: diameter relationship of sheltered seedlings was unusual. Final analysis of the relative success of sheltered seedlings will be made some time after the shelters decompose or are removed.

Consistent trends of increased height and diameter with greater numbers of FOLR were significant and still especially pronounced for the sheltered seedlings.

CONCLUSIONS

1. Lower bed density increased the proportion of seedlings produced that had at least seven FOLR to 60% for not undercut seedlings and 80% for undercut seedlings. Lowering bed density produced the greatest gain in numbers of FOLR.

2. Undercutting increased the number of FOLR lifted with the seedlings, particularly for seedlings grown at lower densities. For taprooted species that are likely to leave many roots in the nursery bed when lifted by traditional methods, undercutting can enhance bareroot seedling root systems. However, undercutting also decreased average seedling shoot size.

3. Evaluation of seedling root systems should be included as a part of routine grading procedures. Black walnut seedlings with seven or more FOLR are more likely to survive and

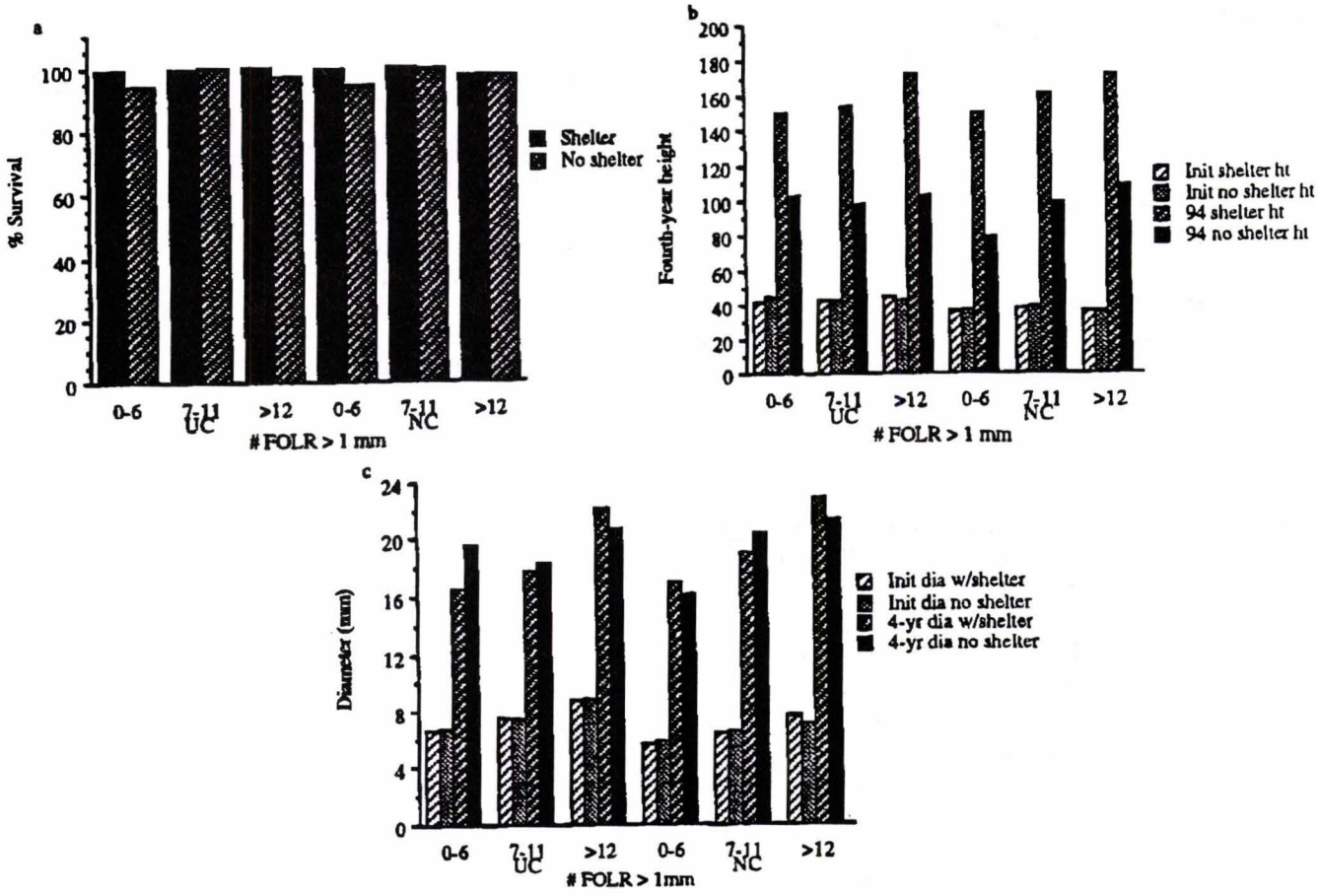

Figure 4.—Effects of FOLR, undercutting, and tree shelters on fourth-year (a) survival, (b) height, and (c) diameter of black walnut grown in Iowa.

grow rapidly after outplanting. Morphological root system assessment is rapid and inexpensive, and could be easily integrated into existing grading procedures.

4. Preliminary testing of seedlings from different parent trees indicates that genetic improvement of seedling root system morphology for black walnut is possible. Further study should be given to the use of root morphology as a possible selection criteria.

5. Although height differences were dramatic between sheltered and unsheltered seedlings, final recommendations on the use of shelters will not be made until some time after the shelters have been removed. Even for sheltered seedlings there were significant height and diameter increases with increasing number of seedling FOLR.

ACKNOWLEDGMENTS

This study was supported by USDA Forest Service State and Private Forestry and McIntire-Stennis funds. We thank Mr. C. Bathrick, Mr. J. Briggs, Mr. G. Grebasch, Mr. R. Jacob, Dr. C. Mize, Dr. R. Overton, Mr. S. Pequignot, Mr. A. Stauder, Mr. D. Westerfer, Dr. J. Wichman, Mr. F. Woods, and Mr. W. Yoder for their assistance and cooperation in this project.

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CHEMICAL WEED CONTROL BEFORE AND AFTER PLANTING WALNUT

John R. Siefert[1]

ABSTRACT.—Weed control is the single most important early cultural treatment necessary for establishing black walnut seedlings. The use and application of a herbicide depends on the characteristics of the active ingredient (mode of action) and the type of weeds. Herbicides can be either downwardly mobile, upwardly mobile, or non-translocated. Research results from eight herbicide studies with black walnut and other hardwoods are summarized.

INTRODUCTION

Of all the hardwood species planted in plantations, black walnut (*Juglans nigra* L.) is clearly the most economically valuable species and by most standards, the most difficult to successfully grow in a plantation. There have been many successful plantations established over the past 30 years, and almost all have had a rigorous approach to controlling weeds. The need for weed control is equal in importance to proper site selection for vigorous growth from seedling stock. Weed control, and in most cases, chemical weed control, is the single most important early cultural treatment. Controlling weeds is especially important since black walnut grows best on deep well-drained soils, which typically are the most productive sites on the landscape. Many of these sites are stream and river bottom sites that have tremendous growth potential for trees as well as weeds. In these types of sites, seedlings must compete with the weeds for the essentials of life - light, water, nutrients, and growing space. Also research suggests that many plants (weeds) complete at a chemical level (allelopathy) with each other and with tree seedlings.

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PLANT FACTORS

Weeds simply are plants growing where they are not wanted. These weeds can be classified into two broad groups: 1) woody plants, including undesirable trees, shrubs, and vines and 2) herbaceous plants, such as grasses, sedges, and broadleaf species. It is especially important to be able to recognize weed groups present and potential invasions so that the appropriate herbicide(s) can be prescribed. A successful weed control program involves consideration of equipment, personnel, financial, and environmental constraints.

Plant factors that must be considered in a chemical weed control program include the type of weed (grass or broadleaf) but also the plant life cycle (annual, biennial, or perennial). Most plants are either 1) grasses or 2) broadleaves. Broadleaf plants include herbaceous forbs as well as many woody plants. Sedges and ferns are neither grasses, nor broadleaves.

Grass seedlings have only one leaf as they emerge from the seed. Their leaves are generally narrow and upright with parallel veins. Most grasses have fibrous root systems. The growing point on seedling grasses is sheathed and located below the soil surface. The growing point gradually moves above the soil as the plant grows and matures.

Herbaceous (plants that do not develop persistent woody tissue above ground) broadleaf seedlings have two leaves as they emerge from the

seed. Their leaves are generally broad with net-like veins. Broadleaves usually have a taproot and a relatively coarse root system. All actively growing broadleaf plants have exposed growing points at the end of each stem and in the leaf axil.

A plant's life cycle is either annual, biennial, or perennial. Annual plants complete the four stages of development in less than 12 months. Winter annuals germinate in the fall, overwinter, mature, set seed, and die in the spring. For best results, control winter annuals at or soon after germination in the fall. Summer annuals germinate in the spring, grow, set seed and die in the fall. For best results, control summer annuals at or soon after germination in the seedling stage of growth.

Biennial plants complete their life cycle in 2 years. They complete the seedling and vegetative stages of growth in the first year, and seed production and maturity stages in the second year. Biennial weeds are most easily controlled in their first year of growth.

Perennial plants may complete all four stages in the first year and then repeat the vegetative, seed production, and maturity stages for additional years, or seed production and maturity stages may be delayed for several years. Some perennial plants die back in the maturity stage each winter. Others, such as trees, may lose their leaves but stems do not die back to the ground. They all reproduce by seed but many are able to spread and reproduce vegetatively with stolons (horizontal stems running on the soil surface) or rhizomes (underground horizontal stems modified for food storage and asexual reproduction). Perennials are difficult to control due to their persistent root systems.

HERBICIDE PROPERTIES AND CHARACTERISTICS

HERBICIDE MODES OF ACTION

The use and application of a herbicide depends on the characteristic of the active ingredient including: 1) whether absorbed by the foliage or roots, 2) whether a contact or translocated herbicide, 3) whether selective or non-selective, and 4) how persistent or non-persistent it is in the environment. Effective weed control can be accomplished by understanding the characteristics of the different herbicides that maybe labeled for black walnut. Herbicides labeled for application around walnut seedlings and saplings can vary for different states.

The mode of action describes herbicide effects at the cellular level of the plant. The mode of action determines movement pattern and injury symptoms. Selectivity on crops and weeds, behavior in the soil and use patterns are less predictable, but are often similar for herbicides with the same mode of action. Vital living metabolic plant processes that may be the target for herbicide action include: 1) photosynthesis (capture of light energy and carbohydrate synthesis), 2) amino acid and protein synthesis, 3) fat (lipid) synthesis, 4) pigment synthesis, 5) nucleic acid synthesis, 6) respiration, 7) energy transfer, 8) growth and differentiation, 9) mitosis (cell division), 10) meiosis (division resulting in gamete and seed formation), 11) uptake of ions and molecules, and 12) translocation of ions and molecules. Disrupting one or more of these processes will result in injury or death to the plant.

There are three general movement patterns associated with herbicides. The first is the downward (symplastic) movement of sugars from the leaves to roots and growing points. The second is the upward movement (apoplastic) of water from the soil to leaf surfaces. The final movement is no movement at all (Ross and Childs 1996).

DOWNWARDLY MOBILE HERBICIDES

Movement from leaves (sources of sugar production) with sugars to sites of metabolic activity (sinks of sugar utilization) such as underground meristems (root tips), shoot meristems (shoot tips), storage organs and other live tissues is the normal mode of activity. These herbicides have the potential to kill perennial and creeping perennial weeds with only one or two foliar applications.

Symptoms are evident on new growth first and may include pigment loss (yellow or white), stoppage of growth, and distorted (malformed) new growth. Symptoms normally appear only after several days and plants die slowly.

Roundup Plus, Accord, and Touchdown are three herbicides that can be used in walnut plantations for weed control. These herbicides are know as aromatic amino acid inhibitors. The products are broad-spectrum, postemergence herbicides that are readily translocated to the roots from the leaves and in some cases from the bark. They have almost no selectivity and will injure or kill most plants if applied to green foliage or green bark. There is no rapid foliage injury and symptom development on annual weeds may require a week or more and perennial weeds even longer. Symptomology of these herbicides is a yellowing of the new growth. Low spray volumes produce better control results. Perennial weeds are more easily controlled up to flowering stage. Late summer to early fall applications can produce better results at lower rates. There is very little soil activity at label rates. Dosage rates range from 1 to 2 quarts per treated acre.

Oust is considered a branched amino acid inhibitor. The herbicide is absorbed by the foliage and roots and is translocated to the growing points. Shoot meristem growth ceases quickly after absorption into the plant. Root development is poor and secondary roots are shortened producing a "bottlebrush" appearance. Symptom development is very slow and may require 2 to 3 weeks. Color changes in the plant leaves can be yellow, red, or purple. The herbicide has increasing soil activity and persistence with increasing rates. Broad-spectrum control of grasses and herbaceous weeds with residual activity make this a unique product. Dosage rates range from 0.75 to 2 ounces per acre after planting. Seifert (1993) showed that rates above 1 ounce reduced walnut growth over all other herbicide treatments including the control and that 0.75 ounce per acre resulted in the best height growth response. Allow adequate rainfall to close the planting slit before application of Oust to newly planted walnut seedlings.

Fusilade DX and Poast/Vantage are considered grass selective herbicides that destroy the plant's meristems. Both products provide the same symptoms on grass species; namely discoloration and disintegration of meristematic tissue just above the nodes. Leaves yellow, redden and sometimes wilt. Annual and perennial grasses are controlled with species varying in sensitivity. Plants other than grasses are not usually injured. The herbicides are foliage absorbed and exhibit little soil activity at the recommended rates. The Fusilade application rate is 16 to 24 ounces per acre. Poast/Vantage rates are from 1.5 to 2.5 pints per acre.

UPWARDLY MOBILE HERBICIDES

These herbicides translocate only upward with the transpiration stream. Symptoms develop from the bottom to the top of the plant shoots (older leaves show most injury; newer leaves least injury). Chlorosis first appears between leaf veins and along the margins which is later followed by death of the tissue. Any potential control of established perennials must come from continued soil uptake and not from movement downward through the plant from the shoots.

Simazine is considered a photosynthetic inhibitor. Application to the soil results in upward movement of the herbicide. Plant reaction is reduction or complete stoppage of photosynthesis in susceptible plants. In plants that have resistance, photosynthesis is slow or unaffected and there is limited effect on root growth. Persistence in the soil is moderate, 8 to 12 weeks at recommended rates. Persistence is largely dependent on rainfall, other weather conditions, and soil factors. Simazine is considered a pre-emergence, soil applied herbicide. It effectively controls most weed seed at germination. Simazine rates are from 2 to 4 pounds of active ingredient (2 to 4 quarts of liquid) per acre. Black walnut shows great tolerance to simazine even at higher than label rates (Wichman and Byrnes 1971).

Surflan and Pendulum are two herbicides that are considered cell division inhibitors. In particular, they are root inhibitors. As such they interfere with the steps in plant cell division responsible for chromosome separation and cell wall formation. As root inhibitors, the herbicides are generally not translocated beyond the roots. Established annual and perennial weeds are seldom killed. Control is most effective on annual grasses. Roots that do not come in contact with the herbicide will not be affect. These products need 1 in. of rain shortly after application to mobilize the herbicide. Early season application is recommended. Both Surflan and Pendulum can be applied at 2 to 4 quarts per acre.

NON-TRANSLOCATED HERBICIDES

Herbicides in this group result in rapid disruption of cell membranes and very rapid kill. Rapid

destruction of cell membranes prevents translocation to other regions of the plant. Severe injury is evident hours after application on most broadleaf weeds. Depending on weed species, grasses and forbs may show injury within a few to several days. New growth of surviving plants will appear normal. Foliar control does not translate to kill the root; thus, weeds may resprout from the roots.

Gramoxone (paraquat) is a foliar applied herbicide which is used as post-emergence only. Application on green tissue (twigs) or leaves of walnut will result in those areas being killed. The herbicide enters the foliage quickly and is rain fast after 30 minutes. Damaged cell walls allow intracellular components to leak into intercellular spaces. This gives the appearance of watersoaked areas. This is a nonselective contact product and is especially suited for control of annual grasses and broadleaves and burndown of perennial shoots. There is no soil activity at the recommended rates. The herbicide is a Restricted Use product that has high mammalian toxicty. Gramoxone can be applied at 2 to 3 pints per acre.

HERBICIDE APPLICATION

Methods of application vary depending on plantation size, available equipment, herbicide formulation, and applicator knowledge. Most herbicide applications will involve at least a pre-emergence herbicide and in many cases the addition of a post-emergence product.

There are two methods of herbicide application: application by hand or mechanized ground sprayer. The preferred method is to mechanize the application and is encouraged for several reasons. First is ease of application. By using a tractor or all-terrain vehicle, constant speed and spray volume can be maintained throughout the application. Spray volume due to pressure and more importantly, ground speed have enormous consequences on application rate. This becomes important for herbicides that are applied on a per acre basis (soil active). Hand application of liquids or granulars can be successful, but requires constant speed and the ability to apply the product evenly and consistently. Also some products require constant agitation which can be difficult to maintain under hand application. Poor weed control or seedling injury is much more prevalent in hand applications than machine application.

The amount of area to be treated in many cases is dictated by the method of application. For most machine applications, a continuous band application is recommended. This method generally provides that from 30 to 50% of the surface area be treated with a herbicide. Also, in some situations, broadcast spraying of the area may be unnecessary. Consideration should be given to the potential for soil erosion. Hand techniques allow for application as circles, squares or continuous bands. Application of a herbicide in a circle is not recommended for soil active herbicides. This is because accurate application rates are much more difficult in a circular motion where the applicator must stop and circle the tree with the nozzle. Squares or bands are preferred in that a constant speed is easier to maintain.

Whether spaying by hand or machine, sprayer calibration is very critical for effective weed control and to prevent seedling injury. This is particularly important with the new herbicide formulations that have a narrow range of activity and are effective at very low rates.

The weed free area around the walnut seedling the first year should be at least 1 ft on all sides and can increase up to 2 ft per side. As the tree grows, (2 to 3 years of age) the treated area should increased to 2 ft per side.

The number of years to maintain weed control after plantation establishment should be a site by site decision. Numerous studies indicate that a 3 year time period is the minimum for good growth. In many cases, this decision is dependent on site productivity, erosion potential, tree spacing, overall plantation growth, and existing as well as anticipated weed populations. Weed control in 15-year-old plantations has increased diameter growth as well as foliar nitrogen levels. On marginal walnut sites where fertility and moisture are limiting factors, continuous weed control will most likely benefit tree growth and nut production. Plantation size is also important from the standpoint that much more sunlight can penetrate the plantation from the edges and stimulate weed development. As plantations age and tree crowns enlarge, shading will reduce the amount of weed competition. The exception will be if cool season perennial grasses such as tall fescue or smooth brome develop. These weed species can be very competitive even in well developed stands. In this scenario, annual weed

control will be necessary until the weeds have been eliminated.

WALNUT RESPONSE TO WEED CONTROL: RESEARCH RESULTS

The following section will present research results from years of field study on the effects of chemical weed control on plantation black walnut. Most studies have shown overall gains from weed control in height, diameter, volume, and in some cases, survival. No studies in the literature have reported negative effects of chemical weed control on the survival and growth of planted black walnut seedlings.

Erdmann and Green (1967) established a study in 1963 in east-central Iowa to evaluate the effect of two ground preparation (fall plowing and spring disking or no ground preparation) and six weed control treatments on the survival and growth of black walnut, red oak, yellow poplar, and white ash (Table 1). Herbicides were applied in April 1963. All species grew best on plots treated with 4 pounds per acre of simazine or atrazine. Black plastic mulch did not increase tree growth over the control. There was no difference in survival between any of the treatments. Weed control did not carry-over into the second growing season.

Byrnes *et al.* (1973) reported 10 year results for survival and growth of a 1963 walnut planting in a bottomland site in Indiana. After 10 growing seasons, walnut survival was 85% for mechanically treated plots to 95% on chemically treated plots (Table 2). Best height and diameter growth

Table 1.—Average 2-year height and diameter growth by weed control treatment with and without preplant site preparation

Weed control treatment	Yellow-poplar		Black walnut		Red oak		White ash	
	Height	Dia.	Height	Dia.	Height	Dia	Height	Dia.
	In.	*32nds*	*In.*	*32nds*	*In.*	*32nds*	*In.*	*32nds*
Atrazine 4lb/acre	48	19	40	16	17	2	31	12
Simazine 4lb/acre	37	12	32	12	14	2	26	10
Atrazine 2lb/acre	29	7	29	8	13	1	20	7
Simazine 2lb/acre	29	7	23	4	11	1	17	5
Plastic mulch	17	1	14	0	8	0	13	3
No weed control	16	0	13	0	8	0	8	0

Table 2.—Average survival, height, and d.b.h. of black walnut 10 growing seasons (fall 1972) after planting 2-year-old seedlings in May 1963

Weed treatment	Survival	Height	D.b.h.
	Percent	*Feet*	*Inches*
None	85	10.1	1.4
Chemical [1]	95	14.5	2.2
Mechanical [2]	85	16.5	2.6

[1] Amizine at 7 lbs/A applied to mil-acre plots around each tree in 1963, 1964, and 1965.
[2] Cultivation of total area with rotary tiller three times per season in 1963, 1964, and 1965.

was achieved on mechanically treated plots over chemically treated plots. The reported growth response occurred in the second year for treated plots, while the control plots did not begin to grow, until the fourth season. They noted that the control plots yearly incremental growth began to equal the treated plots after 4 years, but the total growth was still less than the treated plots. Weed control was discontinued after three seasons.

A second study by Byrnes *et al.* (1973) reported 8 year results for survival and growth of a 1965 walnut planting on a bottomland site in Indiana. After 8 growing seasons, walnut survival was 89% for the control group, 88% for chemical control, and 79% for mechanical control (Table 3). Average seedling height and diameter was greater for chemically treated plots than for cultivated plots, which were both greater than the control. They reported little growth in the control plots for the first 4 years.

Table 3.—Average survival, height, and d.b.h. of black walnut eight growing seasons (fall 1972) after planting 2-year-old seedlings in April 1965

Weed treatment	Survival	Height	D.B.H.
	Percent	*Feet*	*Inches*
None	89	8.0	0.9
Chemical [1]	88	13.4	2.0
Mechanical [2]	79	11.2	1.5

[1] Amizine at 7 lbs/A over entire treatment area in 1965, 1966, and 1967.

[2] Cultivation of total area with rotary tiller three times per season in 1965, 1966, and 1967.

Todhunter and Beineke (1979) reported on a study that was designed to examine the effect fescue grass had on black walnut growth and form. Seedlings were planted in 1971 and the data represents 5 years of growth. Treatments were fescue present or fescue absent from planting site. For the first 2 years after outplanting, simazine and atrazine were sprayed in a 4-ft diameter circle around each tree. Fescue had a significant effect on height, sweep, diameter and volume, but did not influence survival (Table 4).

Table 4.—Effect of fescue on black walnut survival and growth 5 years after planting

Survival and growth	Fescue present	Fescue absent	Improvement
			Percent
Height (ft)	5.99	10.48	75.0
Sweep (ft)	0.15	0.09	46.7
D.b.h. (in.)	0.53	1.57	196.2
Volume (cu ft)	0.0271	0.1323	388.2
Survival (%)	78.5	79.1	0.6

Byrnes *et al.* (1984) reported on a study of black walnut and red oak planted on reclaimed mine land and unmined reference soils in southern Indiana (Table 5). Trees were planted in 1981 and evaluated for 3 years. Simazine, amitrol, and dalapon were applied in meter wide bands in 1981 and 1982. Controlling weeds successfully established walnut on the reclaimed mine site. Reinvasion of the herbicide-treated strips occurred in the third season but was much less on the reclaimed mineland than on the reference soils.

von Althen (1989) reported on the results of a study that investigated the effects of weed control and irrigation on 8 year growth of planted black walnut. The three treatments were mowed for 8 years (control), annual applications of simazine and Roundup, and mowed the first 4 years then chemical weed control the next 4 years. Eight year height increment was 17 cm for the mowed plots, 549 cm for the annual herbicide application, and 260 cm for the plots mowed then chemically treated. The mowed/chemical treatment resulted in nine times as great a height increment the last 4 years than the previous 4 and mimicked annual increment growth of the chemically treated plots. Irrigation had no effect on seedling survival or growth.

Van Sambeek and McBride (1993) reported 10 year results in early growth development of black walnut. Treatments examined the control of fescue using Roundup or simazine, deep ripping and irrigation. Herbicide treatments improved growth more than irrigation or deep ripping. Growth was significantly greater with grass control and no irrigation than with irrigation. Ripping plus grass control, but not ripping alone, improved growth compared with untreated plots.

Table 5.—Average survival and mean net height growth of black walnut and red oak on "chemical control" (Chem) and "no plant control" (Check) areas of reference (Ref) and mineland (Mine) sites 3 years after planting the hardwood seedlings

	Black walnut seedlings				Northern red oak response			
	Check		Chem		Check		Chem	
Year	Ref	Mine	Ref	Mine	Ref	Mine	Ref	Mine
SURVIVAL (percent)								
1981	93	80	94	94	94	70	92	89
1982	84	52	91	72	78	42	75	64
1983	87	29	90	71	80	21	74	64
NET GROWTH (cm)								
1981-83	4	-21	28	20	14	-17	15	3

Table 6.—Average percentage of bare ground in treated area 60 days after treatment and seedling height for five hardwood species 1, 2, and 3 years of chemical weed control

	1992 responses		1993 responses		1994
Treatment	Bare ground	Height	Bare ground	Height	Height
	Percent	cm	Percent	cm	cm
Control	80	31	10	55	66
Oust 0.75 oz	90	35	90	70	86
Oust 1.0 oz	90	37	90	60	82
Oust 2.0 oz	100	32	100	57	60
Simazine 2 lbs/a.i. + atrazine 2 lbs/a.i.	90	36	95	90	163
Simazine 2 lbs/a.i. + atrazine 2 lbs/a.i. + Oust 1.0 oz	100	31	100	65	108
Pendulum 4 lbs/a.i	100	38	100	82	135
Pendulum 4 lbs/a.i. + Oust 1.0 oz	100	31	100	55	88

Seifert (1993) reported the results of seven herbicide combinations on five hardwood species: black cherry, black walnut, green ash, bald cypress, and swamp chestnut oak. Height growth was influenced by herbicide(s) and rates. No difference was noted for survival (Table 6).

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RESPONSE OF BLACK WALNUT TO PREPLANT SUBSOILING AND REPEATED CHEMICAL CONTROL OF TALL FESCUE

F. Danny McBride and J. W. Van Sambeek[1]

ABSTRACT.—Landowners continue to plant seedlings of black walnut (*Juglans nigra* L.) on marginal agricultural lands with shallow fragipans or other restrictive layers. These soils have insufficient available soil moisture during summer droughts for acceptable walnut growth and may produce perched water tables during the dormant season. Preplant subsoiling could increase the effective rooting depth and facilitate water movement through or over the restrictive soil layer. Frequent mowing in these intensively managed walnut plantings also tends to produce heavy grass sods that aggressively compete for limited available soil moisture and nutrients. For our study, we chose a slightly eroded old field ridge in southern Illinois with an 18 to 24 in. fragipan and a tall fescue (*Festuca arundinacea* Schreb.) ground cover.

Initially, we evalulated response of walnut seedlings to all combinations of with and without preplant subsoiling (30 in. deep), with and without irrigation for the first 7 years, and with and without chemical control of tall fescue for the first 8 years. Preplant subsoiling either had no effect or increased sapling growth slightly from 4 to 8 years after establishment. Irrigation had no effect or slowed sapling growth. Chemical weed control had the greatest effect on seedling and sapling growth. Eight years after establishment, trees with annual grass control averaged 14.5 ft tall compared to 6.3 ft for trees without chemical weed conntrol. Stem diameter at breast height averaged 3.9 in. and 1.4 in. for saplings with and without grass control, respectively.

Annual height and stem diameter growth averaged only 1.1 ft and 0.25 inches, respectively, after tall fescue had reinvaded the plots with chemical weed control (10 to 14 years after establishment). Chemical weed control was initiated 16 years after planting to control the invading tall fescue sod in half the plots with and without preplant subsoiling. After only one growing season, walnut trees in plots treated to remove tall fescue had greener foliage, longer leaves, and more branch elongation than walnut trees with a tall fescue ground cover.

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Summary of poster presentation at the fifth Black Walnut Symposium.

THE USE OF TREE SHELTERS IN BLACK WALNUT CULTURE

Felix Ponder, Jr.[1]

ABSTRACT.—Tree shelters are plastic tubes that are placed around seedlings. Tree shelters were first developed in England in the 1970's to protect broadleaf tree seedlings from browsing animals. The microclimatic created by solid tree shelters around the seedling traps carbon dioxide and moisture. Photosynthesis is enhanced by tree shelters which act as miniature greenhouses. Tree shelters are being used and tested in the United States for improving regeneration success. They alter the early growth of a range of tree species, including black walnut.

Growers of black walnut trees are interested in tools and silvicultural methods that can enhance survival, growth, and quality of the species. The establishment phase of black walnut (*Juglans nigra* L.) plantings is characterized by slow growth, animal damage, and poor survival. Wind, soil moisture, and weed control are among factors known to affect the establishment and early growth of black walnut. Wind can act directly upon plants to increase evapotranspiration and mechanical damage. The lack of weed control permits competing vegetation to remove moisture and nutrients from the soil before trees can use them.

The protection of seedlings from browsing animals is critical for the establishment and growth of many tree species in some locations. Many methods can be used to provide plant protection, including fencing, repellents, plastic or metal screens, and tree shelters. Tuley (1985) reported the successful use of "tree shelters" to protect young trees in England. When properly installed, the plastic shelters can also enhance tree growth.

PROTECTION AND SURVIVAL

Newly established or transplanted seedlings are usually the most succulent plants available and can be subjected to heavy browsing pressure. In some cases, rodents, rabbits, and deer easily devour shoots, deform and kill young walnuts unless adequate protection is provided.

Ward and Stephens (1995) reported that after 3 growing seasons, unprotected black walnut seedlings were actually shorter than when planted because of deer browsing. Mortality was also lower for seedlings protected by tree shelters than for unprotected control seedlings. In another study survival of seedlings with tree shelters was no better than seedlings without tree shelters at one planting while at another planting that was established at the same time but on different soils, survival was 82% without tree shelters versus 95% with tree shelters (Ponder 1991). Thus, site may influence the impact of tree shelters on seedling survival. Early U.S. results support findings reported in England (Table 1).

Severeid (1993) has been using tree shelters to protect direct seeded black walnuts. He observed that seedlings had excellent form, good diameter, and adequate height in 2-ft shelters at the end of the first growing season. Trees in 4-ft shelters were tall but spindly. Severeid (1993) attributed the better height growth of these sheltered seedlings, developed from planted seed, to their undisturbed root system. First year growth of bare root seedlings was not as good (Severeid 1993). Although protection from wind is not essential in the establishment of black walnut, wind reduction by tree shelters reduces evapotranspiration and moisture stress (Bainbridge 1994).

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Table 1.—Growth of red oak and black walnut with and without tree shelter in the Central Hardwood Region

State	Species	Age	Height		Survival		Source
			Control	Shelter	Control	Shelter	
		Year	*Feet*		*Percent*		
WV	Red oak	3	3.2	4.6	83	87	Smith 1993
WV	Red oak	3	2.7	4.3	70	75	Smith 1993*
IN	Red oak	3	1.6	2.1	87	82	Minter *et al.* 1992
MO	Bl. walnut	1	0.8	1.5	86	90	Ponder 1991
OH	Red oak	1	0.5	0.7	48	80	Windell 1991
MI	Red oak	3	2.6	4.3	90	98	Langtagne *et al.* 1990
CT	Bl. walnut	3	0.9	3.0	92	100	Ward and Stephens 1995

*Natural seedlings

Tree shelters appear to be most effective in improving survival under difficult conditions, such as where deer or rabbit browsing is a major threat to successful regeneration. The increased number of established black walnuts on these sites has often been associated with protection from browsing.

EARLY ACCELERATED HEIGHT GROWTH

Tree shelters provide an additional advantage, by altering the microclimatic inside the shelter, height growth is significantly increased over unsheltered seedlings (Table 1). Temperature and humidity levels are higher inside shelters (Potter 1991, Ponder 1995), and carbon dioxide (CO_2) levels are also increased when the bottom of the shelter and soil form an effective seal (Table 2) (Frearson and Weiss 1987). The temperature differential between outside and inside of the tree shelter causes the formation of condensation which increases the humidity inside the shelter. This condensation collects on the walls of the shelter and moves down the walls to the soil providing moisture to the tree. Also because tree shelters reduce moisture loss from transpiration and evaporation, more soil moisture for young tree growth is available. Elevated humidity and reduced air movement inside tree shelters, when properly installed around plants, are also believed to be partially responsible for the increased growth.

Table 2.—Seedling growth 16 weeks after planting and mean temperature and carbon dioxide levels inside tree shelters installed differently (Frearson and Weiss 1987)

Treatment	Height	Temperature[1]	CO_2[1]
	In.	*°C*	*ppm*
Soil sealed (blocking) around bottom of tree shelter	25.0	25.5	610
Soil not sealed around bottom of tree shelter	15.6	24.4	450

[1] Ambient temperature is 18.7°C and ambient CO_2 level is 300 ppm.

Tree shelters allow trees to become established quickly and depending on the height of the shelter, stem length soon exceeds the length of the shelter. Once the tops of trees are out of shelters, height growth decreases as diameter growth increases. Tree shelters must be left in place for support after trees emerge from the tops of shelters until they develop sturdy stems with adequate diameters. By favoring height growth over diameter growth, it may be possible to encourage high valued species to a desired height prior to the onset of major branch development (Beetson *et al.* 1991).

Roussel (1972) and LeDousall (1975) attributed the increase in stem elongation to reduced light inside the shelter. The protection from wind provided by shelters may also play a part in the accelerated stem elongation of sheltered seedlings; however it is not clear how wind protection contributes to the increased stem elongation. In greenhouse experiments with sweet gum (*Liquidambar styraciflua* L), seedlings that were shaken to simulate wind effects had less height growth, fewer nodes and less lateral branches, and set terminal buds early (Neel and Harris 1971,1972). Trees that were not shaken did not form terminal buds. These authors strongly suggest that the shaking produces a growth influencing or triggering mechanism of hormonal control over apical growth seems to be at work. Also contributing to this effect may be an increase in the production of ethylene in swaying stems (Kramer and Kozlowski 1979).

COST AND SOURCES

Cost is a major drawback to the use of tree shelters. Table 3 shows prices and characteristics of some tree shelters. They are available in a variety of sizes (18 to over 72 in. tall and 2 to 6 in. in diameter) and shapes (square, circular, or hexagonal). Because tree shelters are so new, there is no long-term research to strongly predict that a modest reduction in rotation age attributed to tree shelters can justify the expense associated with their use. Purchasing and installing shelters can cost over $3.00 per seedling. Shelter cost can be reduced by installing fewer shelters per acre in plantings where regeneration success without tree shelters is predictable; for example, install 40 to 50 shelters per acre as reluctantly suggested by Minter *et al.* (1992) and Kittredge *et al.* (1992) rather than 400. Using fewer shelters around widely spaced high quality seedlings can also reduce costs related to the installation process. Fewer shelters also means less time spent on maintenance such as replacing broken or rotten stakes or setting toppled shelters upright. If the shelter is being used primarily for protection, the length of the shelter selected for a given site should be based on the specific threat present. For example, if rabbits are the main problem, a 2 to 3 ft shelter is probably adequate. If deer browsing is the threat, then 5 or 6 ft shelters may be needed.

Commercial tree shelters were first introduced into the United States by a company called TUBEX. Before shelters were widely available, some investigators made them from sheets of plastic (Personal Communication from Kieth Windell). There are a number of tree shelter companies now in existence. Some of those companies are shown in Table 4. Tree shelter companies characterize their products based on configuration and materials used.

PROBLEMS ASSOCIATED WITH TREE SHELTERS

Dieback from early frost damage and overwintering have been reported on numerous occasions. The longer leaf retention of sheltered seedlings is

Table 3.—Commercially available products, shelter color, percent light transmittance, shape and size of opening, and price per shelter for 1,000 or more 5 ft long shelters (Widdell 1991)

Product	Color	Light transmission	Shape of opening	Size of opening	Price/ shelter[1]
Treehouse	Ivory	25%	Square	4" X 4"	$2.50
Tree Pro	Ivory	NA	Round	4.5"	$2.45
Supertube	Brown	27%	Round	3.5 to 4.5"	$2.60
Blue X	Blue-tinted	NA	Round	4"	$0.40[2]
Tree Sentry	Variable	NA	Round	NA	$2.60
Tree Pee	Ivory	NA	Round	4"	NA

[1] Price does not include stake.
[2] Shelter is 17" long and price includes 24" stake.
NA = Not available

Table 4.—Tree shelter companies and a description of their shelters (Bainbridge 1994)

Name	Address	Description
Tubex or Supertubes	Treessentials Company 75 Bidwell Street, Suite 105 St. Paul, MN 55107 (800) 248-8239	Tree shelters are available in a wide range of heights, nested in groups of four, and easy to install. They can be reused for several years.
Tree Pee	Baileys 44650 Hwy 101, Box 550 Laytonville, CA 95454 (707) 984-6133	Tree Pee shelters are made of recycled polyethylene with UV stabilizer. The shelter is a 24-in. tall cone (8-in. base with 4-in. top) with 3 built-in mounting pins.
Tree Sentry	Tree Sentry P.O. Box 607 Perrysburg, OH 43552 (419) 872-6950	The Tree Sentry shelter is an open-rolled tube made of polyethylene. The shelter can be opened to look at the seedling.
Tree Pro	Tree Pro Tree Protectors 445 Lourdes Lane Lafayette, IN 47905 (317) 463-1011	Tree Pro shelters are made of single-faced polyethylene and are assembled on site. The top is flared to reduce damage.
Blue X	Blue X Tree Shelters 3120 High Street Sacramento, CA 95815 (916) 922-9319	Blue X products are fabricated from transparent blue-tinted polyester film that degrades in about 5 years.

believed to delay the "harden-off" process causing trees to be susceptible to early frost. It has been suggested that this damage could be reduced or eliminated by raising shelters a few inches from the ground in the fall to allow air to circulate and seedlings to harden-off more normally. Experimental evidence to support this claim is lacking. Raising the shelters also exposes the seedlings to increased opportunity for rodent damage. Ventilated tree shelters and tree shelters that wrap around seedlings and are connected together with fasteners that can be easily opened are designed to help seedlings harden-off. However the growth of seedlings in ventilated shelters was no better than the growth of control seedlings after the first year of growth (Costello *et al.* 1991). Late frosts in the spring may damage developing shoots.

Factors which affect the physiology of young trees, predisposing them to conditions that further affect their health should not be overlooked. Allen (1994) reported that more insects and diseases attacked sheltered seedlings than unsheltered seedlings but growth was not affected.

Except for the Tree Pee shelter, tree shelters need a stake to support them; but, the breakage of wood stakes is high. Breakage may occur at installation because of flaws in the stake and may rot or be eaten by termites before the desired shelter life span is reached. Larger wooden stakes and metal stakes made from reinforcement rods or electrical conduit can be used. One-inch diameter PVC pipe can also be used. In cases when shelters may be used for rubbing by large animals, metal posts for stakes may be considered. Some users in England install shelters with 4 in. diameter posts and then wrap both post and shelter with barbed wire in agroforestry trials.

The appearance of large number of shelters can cause public concern. The white translucent polypropylene presents a gravestone appearance. Pale green and brown colored shelters are available. Appearance may also be a concern later when the plastic disintegrates.

Light transmittance of shelters is usually not a problem when used in open areas. Colored tubes transmit less light compared to clear ones. Colored tubes may also change the spectral quality of the light more than clear shelters. The manufacturer of Blue X shelters claims that the blue-tinted tubes admit up to 200% more light used by plants and blocks harmful ultraviolet light.

Mice and voles can be a problem when tree shelters are installed in areas where their numbers are large. The pests girdle tree stems and eat plants, seeds, (in cases when seed is planted rather than seedlings) and in some cases become residents in the shelters. If surrounding vegetation is controlled, rodent damage should be minimal because hawks and owls will be able to catch them as they run between shelters. Tree shelters can trap birds and lizards (Bainbridge 1994). Nets or cross-threaded fishing line at the top of the shelter can minimize the bird problem, but may distort trees emerging from shelters. Leaving a vertical stick in the shelter will enable lizards to climb out.

Wasp nest inside shelters can distorts seedlings. Wasp stings are painful and can be harmful to individuals having allergic reactions to them. A small number of stems become distorted when they become snagged between the shelter wall and the tie slip. Some trees gradually spiraled against the interior of the shelter until emerging.

Experience has shown that it is usually futile to try to use shelters over seed pressed into the ground or planted in areas where wood mice and other tunneling pests are abundant. They reduce regeneration by collecting the seeds and as well as eating tender emerging seedlings.

There has not been any reports on temperatures and humidities inside overwintering shelters with trees. Temperatures over 48°C (118°F) during the growing season have been recorded in shelters in England (Tuley 1985). The trees survived, but not without some leaf damage. Some leaf damage has been reported for trees growing in shelters in California when temperatures exceeded 51.7°C (125°F).

SUMMARY

Test results have shown tree shelters to be effective in protecting young trees from browsing animals. The length of the shelter determines the browse line. Protecting the accelerated height growth of sheltered trees could mean a significant reduction in the time required for seedlings to develop stems above the browse line.

Tree shelters are not a plant and walk away alternative (Smith 1993). Tree shelters fail for many reasons, including rotting stakes, animal damage, broken ties, improper installation (soil does not form a seal at the bottom of the shelter), and poor weed control which contribute to large mice and vole populations.

Cost is a drawback to tree shelter use. Tree shelters can be purchased in large numbers for about $2.00 to $3.00 each. Additional costs include installation and maintenance of the shelters and the control of vegetative competition. Using fewer shelters with good planting stock on suitable sites could increase the number of acres successfully regenerated.

After weighing the pros and cons presented here about tree shelters, you may want more information. Suggestions include visiting a nursery or walnut grower using tree shelters, reading manufacturers' literature or talking with or consult an extension forester about their use.

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USE OF ORGANIC, PLASTIC, AND LIVING MULCHES FOR ESTABLISHING AND MAINTAINING BLACK WALNUT PLANTINGS

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ABSTRACT.—Management objectives, site characteristics, and availability of equipment and labor all influence the ground covers found in managed black walnut plantings. The chosen ground cover can significantly affect tree growth, quality, and nut production through its influence on soil microenvironment, on competition for soil moisture and nutrients, and on presence of allelochemicals and pests. Organic, plastic film, and living mulches can be viable alternatives to supplement chemical weed control and cultivation during establishment and subsequent maintenance of walnut plantings. Organic mulches such as straw, leaves, or decomposed bark and wood chips will moderate soil temperatures within the walnut root zone and can effectively prevent most weed seeds from germinating. Unfortunately, mulch materials may be expensive or not readily available, quickly decompose, and application may be labor intensive. Plastic films can be a more permanent mulch than organic mulches. Soil temperatures under opaque plastic films are heavily dependent on the amount of solar radiation reaching the mulch, the color of the mulch, the boundary layer between the plastic and the soil, and the amount of moisture in the soil. Light colored opaque plastic mulches absorb less solar radiation and heat the soil less than dark-colored plastic mulches. Heat transfer into the soil is greatest when plastic films are in close contact with the soil or under conditions of low available soil moisture.

Most grasses are easily established and grow well under the light shade produced by walnut. Unfortunately, grass sods like tall fescue and bromegrass can significantly reduce soil nitrate nitrogen resulting in reduced tree growth and nut production. Legume ground covers like hairy vetch and crownvetch apparently increase available soil nitrogen resulting in more rapid tree growth and increased nut production. Commercial seed houses offer a wide range of grasses, forbs, and legumes that could be used as ground covers. Unfortunately, many of the legumes with high rates of nitrogen fixation show little or no shade tolerance and may not persist in walnut plantings managed for timber-only when CCFs reach 80 to 110 or more. Walnut plantings managed for timber and nut production will have CCFs below 80 and will support many of the more shade tolerant legumes. With the increasing emphasis on including walnut plantings in agroforestry programs, we must begin to evaluate the effects of different ground covers on our ability to mechanically harvest nuts from these managed plantings.

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WALNUT FERTILIZATION AND RECOMMENDATIONS FOR WOOD AND NUT PRODUCTION

Felix Ponder, Jr.[1]

ABSTRACT.—Fertilization treatments have the potential for increasing black walnut (*Juglans nigra* L.) growth and nut production. Black walnut interplanted with nitrogen fixing plants might also benefit from the biologically fixed nitrogen. The lack of long-term fertilization studies limit our ability to satisfactorily diagnose and prescribe adequate fertilizer treatments. Fertilization should be considered only as a supplement to other basic cultural practices, rather than as a replacement for them, in efforts to increase productivity during the different growth stages of the tree or stand.

NUTRIENT AND FERTILIZATION CONCEPTS

The purpose of fertilization is to increase plant growth and/or fruit production by increasing the available supply of one or more nutrients. However, in the case of black walnut (*Juglans nigra* L.), the influence of site factors including inherent nutrient supply is not always apparent before fertilization. Inherent differences among areas in a site or stand such as poor internal drainage, shallow soil, poor weed control, and compacted soil layers are site factors that may influence the growth response to fertilization. Also, while the nutrient demand for height and diameter growth may be adequate, nutrient demands in response to nut production maybe inadequate.

The benefits of fertilization on black walnut should be most pronounced on sites having adequate physical content for growing the species. The elements essential for normal growth of walnuts and all other green plants are often listed as major elements (macronutrients), which are required in large amounts, and minor elements (microelements) which are required in small amounts only (Table 1). These elements are considered essential because their absence can be demonstrated to cause injury, abnormal development, or death of the plant.

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Maintaining the proper pH is important in any fertilization program. The pH should be maintained between 6.0 and 7.2. The pH should be corrected during site preparation and tested periodically to detect any change in pH. Lime is usually added to raise the pH of most soils to the desired level. The amended pH can be expected to last from 3 to 5 years.

Table 1.—Major and minor elements shown to be important in black walnut nutrition (Phares and Finn 1971)

Source	Major elements	Minor elements
Air and water	Carbon, hydrogen, and oxygen	
Soil	Nitrogen, phosphorus, potassium, calcium, magnesium, sulfur	Iron, manganese, boron, zinc, copper, molybdenum

The use of cover crops and nurse crops that significantly increase soil nitrogen has been extensively studied in plantation management of black walnut (Funk *et al.* 1979, Van Sambeek *et al.* 1986). In many of these studies, the results have been more promising than with mineral

fertilization. Much of the disappointment associated with the use of mineral fertilization may be due to the short duration of most studies, competition from other species, the relative high cost of fertilizers, and misunderstanding of site factors and their interactions. Long-term fertilization trials are needed to determine the response and duration of treatments and optimum rate of fertilizer application for black walnut.

FERTILIZATION RATES AND TIMING

Another area of concern about fertilizing plantation and natural stands of black walnut is how much should be applied and how often. Nitrogen has been the element most often studied as a fertilizer ingredient in black walnut culture. Nitrogen can be lost by volatilization, denitrification, leaching, surface runoff, excess accumulation in the tree, and removal in prunings.

Considerable nitrogen can be removed in the nuts of black walnut since the kernel, hulls, and husks are high in nitrogen and protein. The nitrogen removed in 2,000 pounds of Persian walnuts (*Juglans regia* L.) and 1,000 pounds almonds [*Prunus dulcis* (Mill) D.A. Webb] has been estimated to be 40 and 50 pounds, respectively (Hasey 1985). Nitrogen estimates based on crude protein content of black walnut kernels and the percent nitrogen in husks and hulls show that as much as 44 pounds of nitrogen may be removed for 1,000 pounds of nuts according to laboratory tests on black walnut husks and hulls by the University of Missouri Department of Food Science & Nutrition and Hammons Products Company (1996). Therefore, the stage of development of the trees when fertilized could mean applying fertilizers in amounts above rates needed for increased growth to sustain nut production.

Leaf analysis is a useful tool in locating deficiency of various elements and thus the potential for predicting the beneficial use of fertilizers. Phares and Finn (1971) have tentatively established normal and deficiency ranges for elements with some overlapping values. When a leaf analysis value lies in the overlapping zone, deficiencies may or may not be present. Leaf analysis can be used to measure uptake following an application of a given nutrient to determine if the nutrient was taken up by the tree. Leaf analysis can also be used to identify toxic symptoms, distinguish between herbicide injury and nutrient disorders, but most important the tree can be monitored and fertilized before a deficiency occurs. Although, fertilization guidelines can be based on either soil or plant-tissue nutrient content, foliar analysis is preferred for woody plants (Lavender 1970). The major disadvantage of leaf analysis is that it supplies little information about the soil. Leaf and soil nutrient data when used together is a better predictor of the nutrient needs for black walnut. However, there is a critical need for better soil nutrient data to determine more exact boundaries where a response to fertilization can be expected.

To diagnose fertilization needs based on foliar analysis, Phares and Finn (1971) suggested that foliar nitrogen should be in the range of 2.0 to 2.6%, phosphorus in the range of 0.10 to 0.25%, and potassium in the range of 0.75 to 1.30%, respectively. The likelihood is that black walnut will probably respond when foliar values are less than these rather than when levels are higher. The leaf analysis values developed by these authors were based on seedlings and should not be considered as an infallible guide on which to base fertilization needs, but it is the best guide available to identify black walnut nutrient needs.

TIMBER AND NUTS

Black walnut fertilizer studies have been directed toward improving the quality and the yield of timber and nuts from individual trees in natural and planted stands. The value of black walnut logs is directly related to tree size; therefore the manager wants to produce a merchantable log in the shortest period. Also, the value of the individual walnut trees varies greatly, even if they are of similar sizes. While proportionately more fertilizer studies have investigated growth in response to treatments, a few have also looked at nut production (Ponder 1976, Garrett *et al.* 1991, Jones *et al.* 1993). The purpose of the present review is to provide information to help managers make decisions on the potential benefits that fertilization might have on their black walnut trees at different stages of growth.

WALNUT PLANTATIONS

FERTILIZING NEW PLANTATIONS

Fertilization at the time of planting has not been encouraged because of the potential for increased

weed competition. Beineke (1986) states, "Under no circumstances should seedlings be fertilized the year of planting." It has been shown that black walnut seedlings planted on good sites do not exhibit significant or practical responses to fertilization at the time of planting. Braun and Byrnes (1982) reported that fertilized trees were not significantly larger than unfertilized trees after 12 years when fertilized at ages 1, 2, and 6 years after planting on a good site (Table 2).

Table 2.—Mean height and diameter-at-breast-height (D.B.H.) of 12-year-old black walnut fertilized at 1, 2, and 6 years after planting (Braun and Byrnes 1982)

Treatment[1]				
N	P	K	Height	D.B.H.
— *lbs/acre* —			*Feet*	*Inches*
0	0	0	26.2	5.4
0	0	140	28.5	5.9
0	60	0	29.9	5.7
400	0	0	29.9	5.9
0	60	140	31.2	6.3
400	60	0	28.5	5.7
400	60	140	29.9	6.2

[1]N=nitrogen, P=phosphorus, K=potassium

Research by Dierauf and Garner (1981) showed that good weed control during the first 3 or 4 years may be as beneficial as fertilization (Table 3). Depending on the method of fertilizer application, newly planted black walnut seedlings may be damaged by the fertilizer. Williams (1974) reported that fertilization reduced survival and growth of planted seedlings. Seedling roots probably were dehydrated by fertilizer because of the close proximity to each other.

Funk (1976) reported that mixing fertilizer in the planting hole severely retarded height on a marginal site for the species (Table 4). However, by age 7 and after subsequent surface applications of fertilizers, the surviving fertilized trees were taller and larger in diameter than unfertilized trees (Ponder 1980). The mean height growth for fertilized trees was 2.6 ft compared to 2.3 ft for unfertilized trees.

FERTILIZATION OF YOUNG PLANTATIONS

An Indiana planting, growing on suitable soil, was fertilized the year after planting and again in years 3 and 7 (Braun and Byrnes 1982). No statistical height or diameter growth differences were detected during the study. In another study, von Althen (1985) eliminated 90% of the

Table 3.—Two-year height growth response of young black walnut trees to fertilizer and herbicide applied at various ages (Dierauf and Garner 1981)

Tree age (years)	Fertilizer applied	Herbicide applied	Height growth	Height growth range
			- - - *Feet* - - -	
1 to 3	yes	yes	1.3	-0.6 to 4.7
4	yes	yes	0.8	-0.3 to 1.9
5	yes	yes	0.6	-1.3 to 2.3
6	yes	yes	0.9	0.1 to 1.5
1	yes	no	1.0	-0.2 to 2.1
0	no	yes	2.6	0.8 to 5.9
2	no	yes	1.2	0.2 to 2.3
3	no	yes	1.4	0.0 to 3.1
4	no	yes	0.9	0.6 to 1.3

Table 4.—Cumulative height of black walnut fertilized at planting with 12-12-12- fertilizer by different methods after years 5 and 7 according to Funk (1976) and Ponder (1980)

Method	Application rate	Height at year 5	Height at year 7
	oz/tree	*Feet*	*Feet*
None	0	8.1	10.4
Broadcast	4	8.5	11.1
	8	9.4	11.7
	12	9.8	12.7
Hole	4	9.1	11.7
	8	9.1	11.7
	12	9.4	12.0
Mixed	4	9.1	11.7
	8	9.8	12.4
	12	10.1	12.7

weeds and fertilized an 8-year-old plantation in Ontario, Canada. Plots received weed control and were fertilized three successive years with either 220 or 440 lbs/acre of elemental nitrogen. Weed control increased 4-year height and diameter growth of the walnut trees by 153%. Fertilization and weed control further increased height and diameter. However, nitrogen fertilization without weed control did not significantly increase growth. These studies are further evidence to suggest that fertilizers are not needed during the early years of walnut plantation establishment.

FERTILIZING POLES AND THINNINGS

Fertilization of pole-size trees is likely to provide the best economic returns (Schlesinger and Funk 1977). An acceptable diameter growth rate of trees at this age and older is about 0.3 in. per year. Pope *et al.* (1982) fertilized a 12-year-old black walnut plantation growing on Martinville silt loam (Table 5). Nitrogen as urea was broadcast over plots at rates of 0, 50, and 100 pounds of elemental nitrogen per acre with and without weed control. Four year height, diameter, and volume growth of the plantation were significantly increased by nitrogen fertilization and weed control. Ponder (1983) fertilized a 10- and a 12-year-old planting growing on a somewhat poorly drained soil. Fertilization stimulated height growth but not diameter growth.

Table 5.—Influence of nitrogen fertilization and herbicide on total height and diameter growth over 4 years (Pope *et al.* 1981)

Fertilizer rate (lbs/acre)	Herbicide applied	Height growth	Diameter growth
		Feet	*Inches*
0	No	6.6 a[1]	0.9 a
0	Yes	7.9 a	1.3 ab
50	No	8.5 ab	1.2 ab
50	Yes	11.1 ab	1.5 b
100	No	11.8 ab	1.7 c
100	Yes	13.5 b	1.8 c

[1]Column values not followed by the same letters are not significantly different at the 0.05 level according to Duncan's New Multiple range test.

Geyer *et al.* (1979) released and fertilized a 40-year-old black walnut plantation that was on strip-mined soils in southeastern Kansas (Table 6). Diameter growth of fertilized trees increased from 27 to 51% in response to 333, 666, or 999 pounds of actual nitrogen per acre over unfertilized trees. Release without fertilization increased growth by 61%, when released and fertilization treatments were combined, growth increased more than 80% over trees not released or fertilized.

Table 6.—Total diameter-at-breast height (D.B.H.) growth of 40-year-old black walnut trees 5 years after release and nitrogen fertilization (Geyer *et al.* 1979)

Fertilization (lbs/acre)	Release	D.B.H.
		Inches
0	No	0.18
0	Yes	0.46
333	No	0.31
333	Yes	0.64
666	No	0.48
666	Yes	0.66
999	No	0.56
999	Yes	0.91

FERTILIZATION OF WALNUT IN NATURAL STANDS

The relative importance of walnut in natural stands ranges widely from a near monoculture, to stands with scattered individuals representing an insignificant portion of the total stand. However, the culture of these individual trees may have merit based on their current and/or potential log quality. Stringer and Wittwer (1985) looked at single-tree release and fertilization in a mixed natural stand of black walnut in central Kentucky. Trees in the 18- to 25-year-old stand averaged 15.9 cm in diameter. Individual trees fertilized with 10 lbs/tree ammonium nitrate yielded a 31% increase in average basal area compared to unfertilized trees over a 3-year period. Application of 5 pounds of ammonium nitrate per tree did not significantly affect diameter growth. Foliar analysis during the second year of the study showed that the foliar nitrogen concentration was in the "intermediate" range according to the recommendations of Phares and Finn (1971) suggesting that additional nitrogen may or may not produce a further growth response. Phares and Finn (1971) indicated that "no probable" response could be expected from adding nitrogen when the leaf nitrogen level is above 2.6%, "some" response at 2.0 to 2.6%, and a "likely" response at levels below 2.0%.

The nitrogen content of black walnut leaves was not significantly increased after release and fertilization in a study on medium textured soils in west-central Missouri (Ponder 1976). Neither was there a significant increase in diameter growth between fertilized and unfertilized trees (Table 7). No trees had leaf nitrogen levels below 2.8%.

Table 7.—Four-year growth and foliar nitrogen, phosphorus, and potassium levels of released and fertilized pole-size black walnut (Ponder 1976)

Treatment				D.B.H.	Foliar nutrients		
N	P	K	Release	growth	N	P	K
(lbs/tree)							
				Inches	*Percent*		
0	0	0	No	0.92	2.80	0.32	1.72
0	0	0	Yes	1.44	2.82	0.22	1.42
10	0	0	Yes	1.35	2.93	0.25	1.34
10	5	0	Yes	1.50	2.86	0.30	1.64
10	0	8	Yes	1.53	2.78	0.25	1.38
10	5	8	Yes	1.47	3.30	0.29	1.57
20	0	0	Yes	1.45	3.18	0.26	1.48
20	10	0	Yes	1.32	3.13	0.30	1.61
20	0	16	Yes	1.52	3.57	0.29	1.52
20	10	16	Yes	1.53	2.86	0.24	1.43

Table 8.—Mean D.B.H. over 10 growing seasons and foliar nitrogen levels for fertilized sawtimber size black walnut on a bottomland and an upland site in Wisconsin (Maeglin *et al.* 1977)

Sites	Treatments	D.B.H. growth	Foliar nitrogen
		Inches	*Percent*
Bottomland	Control	3.4	3.18
	Fertilized	2.2	3.36
Upland	Control	1.4	2.52
	Fertilized	1.4	2.98

Maeglin *et al.* (1977) fertilized 20 pairs of black walnut trees on an upland and on a bottomland with 500 pounds of elemental nitrogen from ammonium nitrate. The material was broadcast by hand around trees in a circle equal to the crown diameter of the tree. Fertilizer was reapplied three times over the 10-year study period. Diameter growth of fertilized trees on the bottomland and the upland were greater than that of control trees, but differences were not significant over the study period or any intermediate period (Table 8). On the bottomland site, except for the first growth period, control trees had significantly greater diameter growth than fertilized trees. Foliar nutrient data showed that nitrogen levels for the upland was 3.0% compared to 3.4% for the bottomland. Maeglin *et al.* (1977) believed that the nitrogen uptake on the bottomland site could be considered at the "luxury" level resulting in an excess that caused the retardation of growth. These authors also point out that, *in vitro*, experiments have shown that excess nitrogen in the presence of high levels of phosphorus and potassium singularly or together will reduce growth. Both soil and foliar tests showed high levels of both elements.

Funk (1976) reported a similar retardation of black walnut growth in Indiana. Sawlog-sized walnut trees, 60- to 80-years-old on a fertile bottomland site had less diameter growth than unfertilized trees (Table 9). Leaf analysis indicated that foliar phosphorus levels were low and that the site may be deficient in phosphorus. The addition of 900 pounds of triple superphosphate per acre did not significantly increase diameter growth. The author surmised that the trees were too old to effectively utilize the added fertilizer and that fertilization of mature black walnut trees on good sites does not appear to be a feasible silvicultural alternative.

Table 9.—Seven-year D.B.H. growth of sawtimber sized black walnut in response to nitrogen and phosphorus fertilization (Funk 1976)

Ammonium nitrate	Triple superphosphate (lbs/acre)			
(lbs/acre)	0	300	600	900
	- - - - *Inches D.B.H.* - - - -			
0	1.8	1.3	1.2	1.2
600	1.6	1.5	1.6	1.1
1,200	1.4	1.1	1.3	1.1
1,800	1.2	1.4	1.5	1.1

In a natural mixed hardwood stand in Wisconsin, black walnut trees 6.5 to 18.7 in. (15.3 to 28.1 cm) in diameter were released before being fertilized at two rates of nitrogen and a single rate of phosphorus and potassium (Ponder and Schlesinger 1986). After 11 years, the best response to fertilization was by trees receiving the highest amount of nitrogen (30 lbs/tree) and in diameters ranging from 14.6 to 18.7 in. (21.9 to 28.1 cm).

BIOLOGICAL NITROGEN FERTILIZATION

An alternative to chemical fertilization of black walnut is to interplant nitrogen-fixing plants. Although nitrogen-fixing plants (trees, shrubs, and herbaceous) may alter the site through adding biologically fixed nitrogen, the most apparent affect has been the increase in growth of the associated plants (Funk *et al.* 1979; Friedrich and Dawson 1984; Van Sambeek 1988, Van Sambeek *et al.* 1985; Clark and Williams 1979; Paschke *et al.* 1989; Schlesinger and Williams 1984; Ponder 1993). Both height and diameter of black walnut planted with nitrogen fixing plants were much greater than when planted alone (Table 10). Most of the reports on

Table 10.—Height and diameter of black walnut grown in mixture with nitrogen fixing species

Study author	Age	Interplanted species	Space between walnut rows	Walnut growth	
				Height	Diameter
	Years		*Feet*	*Feet*	*Inches*
Friedrick and Dawson 1984	14	None	16[1]	4.3	6.4
		Autumn olive	16	9.7	13.1
		European black alder	16	6.2	8.3
		Black locust	16	6.0	8.4
Van Sambeek *et al.* 1986	3	None	10	3.7	0.6
		Hairy vetch	10	4.6	0.7
		Crownvetch	10	4.3	0.6
		Serecia lespedeza	10	4.5	0.6
		Crimson clover	10	4.0	0.6
Ponder 1993	7	None	8[2]	2.5	2.3[3]
		Autumn olive	8	4.6	3.1

[1]Interplanted species are 8 ft from walnut in the row.
[2]Autumn olive is 4 ft from walnut in the row.
[3]Diameter 1 in. above the soil surface.

nitrogen fixing shrubs and trees by these authors are from studies established in Missouri, Illinois, and Indiana by a researcher at the Forestry Sciences Laboratory at Carbondale, IL.

Ponder and Baines (1985) reported that young black walnut trees were taller and larger in diameter when planted in mixture with autumn olive (*Elaeagnus umbellata* Thunb.), a nitrogen fixing shrub, than when fertilized (Table 11).

Table 11.—Height and diameter of black walnut seedlings 5 years after outplanting with cultural treatments (Ponder and Baines 1985)

Treatments	Height	Diameter
	Feet	*Inches*
Mixed[1]	10.5	1.5
Fertilization[2]	6.2	1.0
Control	3.0	0.5

[1]Planted with autumn olive.
[2]Fertilized at a rate of 752 pounds of 12-12-12 per acre.

Reported values for the amount of atmospheric nitrogen fixed by plants such as alder can range to over 300 lbs/acre (Tarrant and Trappe 1971). Reported values for herbaceous legumes range from 51 lbs/acre for soybean (*Glycine max* [L.] Merr.), 82 lbs/acre for vetch (*Vicia* spp.), 84 lbs/acre for crimson clover (*T. incarnatun* L.), 118 lbs/acre for white clover (*T. repens* L.), 133 lbs/acre for red clover (*Trifolium* spp.), 151 lbs/acre for blue lupine (*Lupinus* spp.), and 186 lbs/acre for alfalfa (*Medicago sativa* L.) (Erdman 1967). The biologically fixed nitrogen is apparently made available to the walnut through increased organic matter accumulation and decomposition and is frequently associated with increased nitrate nitrogen in the soil (Ponder 1980). In addition to nitrogen accretion, nitrogen fixing shrubs and trees may serve as windbreaks reducing the effects of wind on evapotranspiration in the trees. Also, in the case of nitrogen fixing trees and shrubs, close-canopy condition in the stand occurs earlier, reducing the grass component of the stand as it develops a more woodsy appearance.

Finn (1953) reported that black walnut, under planted in a decadent black locust stand, was over 7 ft tall four growing seasons later. Foliar nitrogen levels of the walnut averaged 3.2%. On good sites, nitrogen fixing plants are ineffective in

promoting height growth above that of trees planted alone (Schlesinger and Williams 1984). It can be surmised that the application of chemical fertilizers would also be ineffective.

FERTILIZATION AND NUT PRODUCTION

Poor and irregular nut crops have been attributed to a combination of factors including insect damage, unfavorable weather, and soil fertility. Nothing can be done about the weather and the control of insects is difficult and costly, especially when the weather is unfavorable. However, research has shown that nut production can be stimulated by mineral fertilization. Nut production is a nutrient drain on trees which may require routine fertilization annually for normal yields (Romas 1985, Sparks 1975). Weinbaum *et al.* (1984) reported that up to 2.2 lbs of nitrogen /tree could be removed annually in harvested almonds.

Jones *et al.* (1993) reported that late summer fertilization with 6.4 oz (0.18 kg) of nitrogen, phosphorus, and potassium (13-13-13)/cm of tree diameter increased nut production by 32% over spring fertilized trees and by 34% over unfertilized trees (Table 12). Although these authors indicate that the amount of fertilizer applied is considered low, increases in conifer seed production have been reported in response to moderate levels of nitrogen, phosphorus, and potassium applied in late summer (Schmedtling 1993).

Table 12.—Mean 5-year nut production of black walnut trees fertilized at different times of the year (Jones *et al.* 1993)

Treatment		
Time	Fertilizer applied	Nut production
		#/year/tree
Spring	Yes	127.5
Spring	No	125.7
Late summer	Yes	187.0
Late summer	No	122.1

Nut production was increased by fertilization in a natural young pole size walnut stand (Ponder 1976). The largest increase in nut production was associated with phosphorus and potassium. Two levels of nitrogen, phosphorus, and potassium separate and in several combinations did not significantly influence the leaf levels of these nutrients. The dollar value of an enhanced black walnut nut crop has been demonstrated (Garrett *et al.* 1991, Garrett and Kurtz 1983, Jones *et al.* 1993).

SUMMARY

Time your fertilizer applications during the growing season to best fit your cultural operations. Studies have shown that the least efficient time to apply nitrogen is in the winter when roots are less active and least able to absorb it. Losses from dinitrification or leaching can also occur at this time. Nitrogen uptake is most efficient when applied some time during the growing season.

The relationship of nitrogen fertilization to crop production in deciduous tree crops is complex. For example, one study with almonds showed that the later the nitrogen was applied during the growing season, the less nitrogen was recovered in the fruit and leaves that year, but more of this nitrogen was found in the fruit and leaves the following year (Weinbaum *et al.* 1984). What this means is that spring applications will contribute more nitrogen towards the current season's growth. Applications made later in the growing season will contribute more of the nitrogen to the following season's growth. Split applications may work best on sandy soils. It is a good idea to incorporate nitrogen into the soil or water-in soon after application to prevent losses from volatilization. Although, the manager must choose the time of the year to apply fertilizers, it may be more important to decide at what age or stage in the tree stand development may be best for the trees to respond to treatment.

The data presented indicate that fertilization can cause a modest improvement in tree growth in some cases; but, weed control and/or release and interplanting with nitrogen fixing species have increased growth more consistently. Black walnut site requirements are demanding. Fertilization will produce very limited favorable results on unfavorable sites for the species, neither is additional growth likely on sites where trees are already growing well.

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BLACK WALNUT, AGROFORESTRY, AND MUNICIPAL SEWAGE SLUDGE

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ABSTRACT.—Our walnut planting located near Carthage, Missouri is an excellent example of integrating unique opportunities into a successful agroforestry program. In 1979, Hammons Products Company planted approximately 6,000 black walnut seedlings for Carthage Marble Corporation on a 60 acre site near the Spring River. Tree spacing was 10 ft apart within rows and 30 ft between rows. Little or no maintenance was done until 1993 when we contracted to begin cutting out all the invading honey locust and osage orange trees. Most of the walnut had survived and were of acceptable form. The invading trees had created a woods-like condition that provided sufficient shade to minimize branch growth on the lower stem of the walnut trees. Target pruning procedures were used to remove most of the lower branches. Future pruning will need to be done from a pruning tower. Orchard grass was no-till seeded in a thin stand of tall fescue in 1995; however, due to the 1996 drought, the orchard grass will need to be no-till seeded again. The area was permanently fenced into two large areas so that cattle can be rotated between the two pastures. In 1994, we began marking the best nut producing trees with different-colored paint dots so we can use this information when we thin from approximately 110 trees per acre to 75 trees per acre in a few years.

Local agronomists recommend the addition of 200 to 300 pounds of nitrogen (N) annually for production of high-quality grass. We decided to test the feasibility of using sewage sludge from the nearby Carthage sewage plant which was also looking for low-cost, environmentally acceptable options for disposal. Cooperatively, we decided to apply approximately 30,000 gallons per acre of sludge in 30 ft wide strips between the trees twice a year. No sludge was applied on every 10th strip to serve as an unfertilized control, as well as within 300 ft of waterways. Sludge applications were done in the spring and fall during the traditional rainy seasons. Under these conditions, the ammonia smell disappeared within 10 days and the cattle began grazing approximately 20 days later. Chemical analyses of the sludge from this small municipal plant suggest approximately 185 pounds of nitrogen are being applied twice a year. Trace metal accumulation in the nuts was a concern; however, chemical analyses suggested it will require more than 250 years before we are likely to see appreciable deposition of trace metals in the nut crop.

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Landowner Show and Tell Presentation at the Fifth Black Walnut Symposium.

THE EFFECTS OF CROWDING ON BLACK WALNUT TREE GROWTH

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ABSTRACT.—Thinning is one of the most important silvicultural tools available for directing the growth of a forest stand toward specific management goals. Its successful application requires a clear statement of the management goals and a good understanding of the biological characteristics of the species, especially the needs and responses of the trees to growing space, competition, and release. Results from research conducted in the central United States with black walnut (*Juglans nigra* L.) show that this species is very sensitive to crowding, but that crowded trees respond well to release from competition. In several plantings with trees spaced at 3.66 m between rows and 2.44 m within rows, diameter growth decreased when competition, expressed in terms of crown competition factor (CCF), increased beyond 82. Growth reduction appears to be inversely related to CCF and occurs at a rate of 4.3% for each 10-unit increase in CCF. Individual black walnut trees released from competition with other trees grew much faster in diameter than unreleased trees. Even trees with small crowns responded to release. This information provides a basis for developing models to determine the timing and intensity of thinning best suited for various management objectives for this species.

INTRODUCTION

Thinning is one of the most powerful tools available for guiding the development of a forest stand toward specific management objectives. The selection of a thinning strategy depends upon numerous factors, including the desired end products, the site, the initial spacing of the trees, the response of the trees to competition, and the response of the trees to release from competition. Kirkland's (1976) observation that there was not a uniform approach to thinning radiata pine (*Pinus radiata* D. Don) in New Zealand is thus not surprising, and indeed can be expect to hold true for most tree species and locations.

The successful development of thinning strategies requires both a clear statement of the management goals and an understanding of the basic biology underlying the growth of the trees. The two principal end products of management for black walnut (*Juglans nigra* L.) are large, high-quality logs and nuts (Schlesinger and Funk 1977). The management objectives focus on value rather than volume per unit area.

Two general approaches have been used for determining the biological basis for thinning. One is to use extensive field trials that combine various spacings, stocking, and site variables with one or more product objectives. This approach may be satisfactory for species that are widely planted, such as radiata pine (James 1976), ponderosa pine (*Pinus ponderosa* Laws.) (Oliver 1979), or yellow poplar (*Liriodendron tulipifera* L.) (Beck and Della-Bianca 1975). The second approach is to develop growth models using limited field trials (Honer 1972). For species such as black walnut, the second approach holds the most promise.

As part of a program to better understand the biological responses of black walnut to various growth factors, two aspects of the effects of crowding on diameter growth were studied: the relation between levels of competition and tree growth, and the response of diameter growth to release from competition.

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EXPERIMENTAL METHODS

The effects of crowding on diameter growth was studied by analyzing records from 20 walnut plots, 8 located in southern Illinois and 12 in eastern Missouri (Table 1). At each location, the trees in half the plots had been planted at a spacing of 2.44 m by 3.66 m (close spacing) and in the other half at 4.88 m by 3.66 m (wide spacing). Annual measurements of d.b.h. (diameter at 1.37 m above ground) were available for a period of 12 (Missouri) and 13 (Illinois) years. The measurements were made on the interior rows within each plot in order to avoid edge effects.

Table 1.—Characteristics of study locations and plots

Item	Illinois	Missouri
Latitude	37° 30' N	38° 41' N
Longitude	88° 17' W	90° 44' W
Plot size	0.094 ha	0.045 ha
No. trees per plot	105 (close)	50 (close)
	52 (wide)	25 (wide)
No. measured per plot	65 (close)	24 (close)
	32 (wide)	12 (wide)
Year planted	1969	1969
Year first measured	1972	1972
Year last measured	1984	1983
Survival	98.2%	99.1%

The average annual growth was calculated for each plot using the d.b.h. measurements. The measure of stocking for expressing competition was crown competition factor (CCF) (Krajicek *et al.* 1961). CCF is the ratio of the sum of the potential crown areas for all trees within a planting to the actual ground area of the planting, and is usually expressed as a percentage. For example, when the potential crown areas exactly equal the ground area, CCF is equal to 100. CCF values for the close-spaced plots were obtained from previously published tables (Schlesinger 1976).

Black walnut is sensitive to soil moisture conditions (Baker 1921). Therefore, to eliminate the effects of yearly variation in growing conditions, the diameter growth for each of the close-spaced plots was normalized by dividing by the average growth of the four (Illinois) or six (Missouri) wide-spaced plots.

The original data set consisted of 114 normalized diameter growth values and their corresponding CCF values. Initial data screening showed that the growth in one plot in each area was consistently much less than in the others during the first several years before crown closure. The growth in these plots was apparently being affected by factors other than between-tree competition, so the data from these plots were not used. The remain values were summarized into 14 CCF groups of 10 CCF unit size for which means and standard errors were compute. Also, regression analyzes were performed using the individual data points.

The response to release from crowding was studied using growth records from 445 individual trees: 327 had been released from surrounding competition and 118 had not been released. The trees were located in eight areas in Illinois and Indiana (Table 2).

Diameter growth was calculated for each tree for the 10-year period following treatment. In addition to the released versus not-released categories, each tree was assigned to one of three size classes according to its d.b.h. before treatment. Small, medium, and large d.b.h. classes were established for each area using the mean d.b.h. + or - 0.43 standard deviations. For example, trees with diameters less than the mean minus 0.43 standard deviations were classed as small. For a Gaussian distribution of tree diameters, this procedure results in the assignment of about one-third of the trees to each group.

A third factor considered was the before-treatment percent of maximum crown area (%MCA) for each tree. Krajicek's (1966) equation for open-grown black walnut was used for computing the crown width from the tree diameter: Crown width (m) = 0.2392 x d.b.h. (cm) + 1.485. The maximum crown area is the area of a circle with diameter equal to the calculated crown width. The actual crown area was calculated from crown diameter measurements and expressed as a percentage of the maximum. Three categories of original crown sizes were established: small (less than 40%), medium (between 40 and 70%), and large (greater than 70%).

Analysis of variance was used to determine the effects of release, original diameter and original crown size on the 10-year growth following

Table 2.—Characteristics of locations with released trees

Latitude (N)	Longitude (W)	Initial age	Initial d.b.h. (cm)	All	Number released
		Illinois			
37° 44'	89° 7'	25	18.8	77	64
37° 41'	89° 4'	25	20.8	94	67
37° 33'	89° 22'	30	14.7	43	31
		Indiana			
39° 1'	87° 10'	25	17.5	60	48
38° 59'	87° 14'	25	15.2	57	47
41° 6'	85° 27'	65	33.8	42	27
41° 40'	86° 38'	65	34.5	36	25
38° 32'	86° 30'	45	22.4	36	18

treatment. The analyis of variance model was that for a three-factor experiment with unequal replication.

RESULTS

EFFECTS OF CROWDING

The growth in the close-spaced plots and the wide-spaced plots should be similar until between-tree competition occurred in the close-spaced plots: i.e., the normalized growth ratio should be about 1.0 when normalized. Growth in the close-spaced plots should be less than that in the wide-spaced plots once between-tree competition begins in the close-spaced plots, resulting in growth ratios less than 1.0. There were 16 observations for which the growth in the close-spaced plots exceeded that in the wide-spaced plots (i.e., growth ratios of more than 1.0), all occurring at CCF values less than 82 (Fig. 1). At CCF values less than 82, there were also 16 observations with growth ratios less than 1.0.

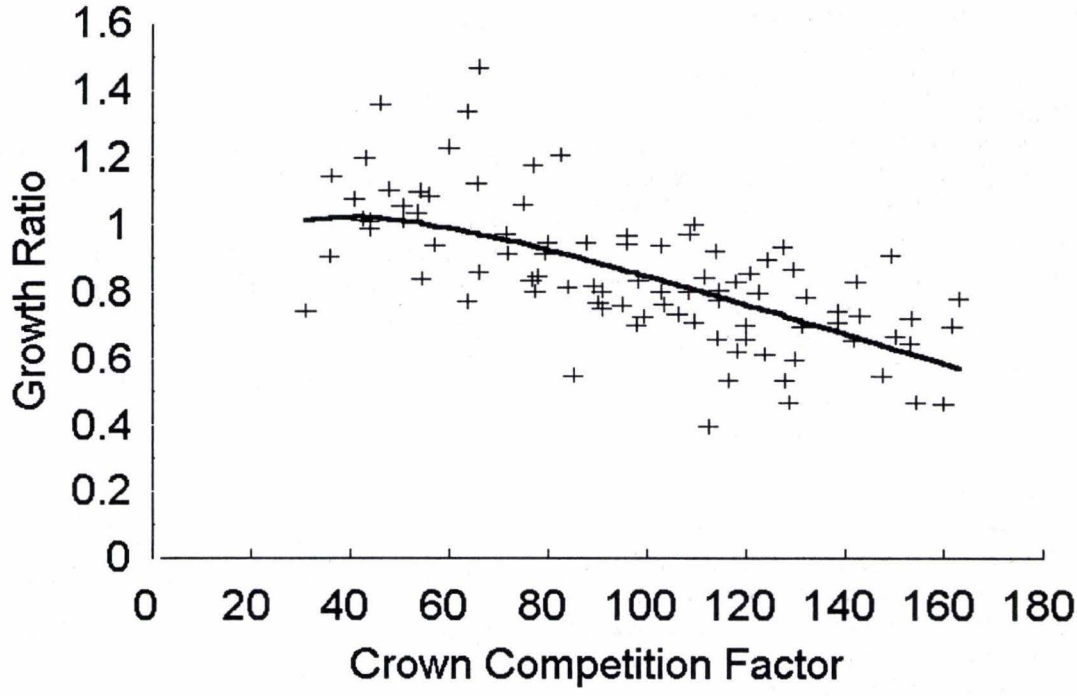

Figure 1.—Relation between normalized growth and degree of crowding.

For CCF greater than 82, all the growth ratios were less than 1.0, indicating a reduction in growth in the close-spaced plots compared with the wide-spaced plots. The average values for the 10-unit CCF groups showed the growth ratio dropping to less than 1.0 for the class centered at 75 CCF (Table 3), and generally becoming smaller as the average CCF levels increased.

The relation between normalized growth and CCF level was best described by an equation including both CCF and 1/CCF:

$$Y = 1.411 - (0.00485 \times X) - (7.643 / X)$$

where Y = growth ratio (close-spaced/wide-spaced) and X = CCF level. This equation has an adjusted R square of 0.418, a standard error of 0.154, and a 32.15 F value.

Although there is obviously much unaccounted for variation in the data (Fig. 1), the relation between normalized growth and CCF level is nearly linear once competition begins, with the reduction in growth amounting to about 4.3% for each 10-unit increase in CCF.

RESPONSE TO RELEASE

Black walnut trees of all stem and crown sizes benefited from release. Released trees grew 47% more during the 10 years following treatment than the unreleased trees. On the average, the trees that were largest at the beginning of the study grew 15% more than the medium-sized trees, and 32% more than the smallest trees. The growth of the medium and small trees was not significantly different.

Original crown size also affected tree growth, as would be expected. The trees with large crowns grew 32% more than those with small crowns (Table 4). Also, the trees with medium crowns grew 19% more than those with small crowns. There were no significant statistical interactions among release, stem size, and/or crown size.

Of particular note was the response of the small trees with small crowns to release. Those trees grew 103% faster than the unreleased group (Fig. 2). Although this group still grew less than the larger trees, the difference is less than between the small and large trees not released.

Table 3.—Growth rates (close-spaced/wide-spaced) for 10-unit CCF groups

CCF group limits	Number of observations	Average CCF	Average ratio
31 - 40	3	34.4	0.930
41 - 50	7	44.1	1.105
51 - 60	8	54.6	1.036
61 - 70	5	65.1	1.110
71 - 80	9	76.4	0.940
81 - 90	5	85.8	0.864
91 - 100	9	95.1	0.806
101 - 110	8	106.5	0.840
111 - 120	9	115.0	0.709
121 - 130	10	124.6	0.732
131 - 140	5	134.3	0.708
141 - 150	5	144.9	0.734
151 - 160	4	152.8	0.625
161 - 170	3	161.6	0.650

Table 4.—Mean 10-year diameter growth (cm) in response to release, original stem diameter, and crown class

Treatment	Released	4.99 a*
	Not released	3.39 b
Original dbh	Large	5.24 a
	Medium	4.55 b
	Small	3.97 b
Crown size	Large	5.26 a
	Medium	4.75 a
	Small	3.99 b

* Means followed by the same letter are not significantly different for alpha = 0.05 according to Scheffe's method of contrast.

DISCUSSION

Because black walnut is sensitive to such growth factors as soil nutrients and soil moisture (Ponder 1981), the reduction in diameter growth with increasing competition is not surprising. However, the fact that the response was first observed at levels well below CCF 100 was somewhat unexpected, because a CCF less than 100 means that all the crown area available to the trees is not yet being used.

One possible explanation for the growth reduction before complete crown closure is that belowground competition may occur before aboveground competition. The available information

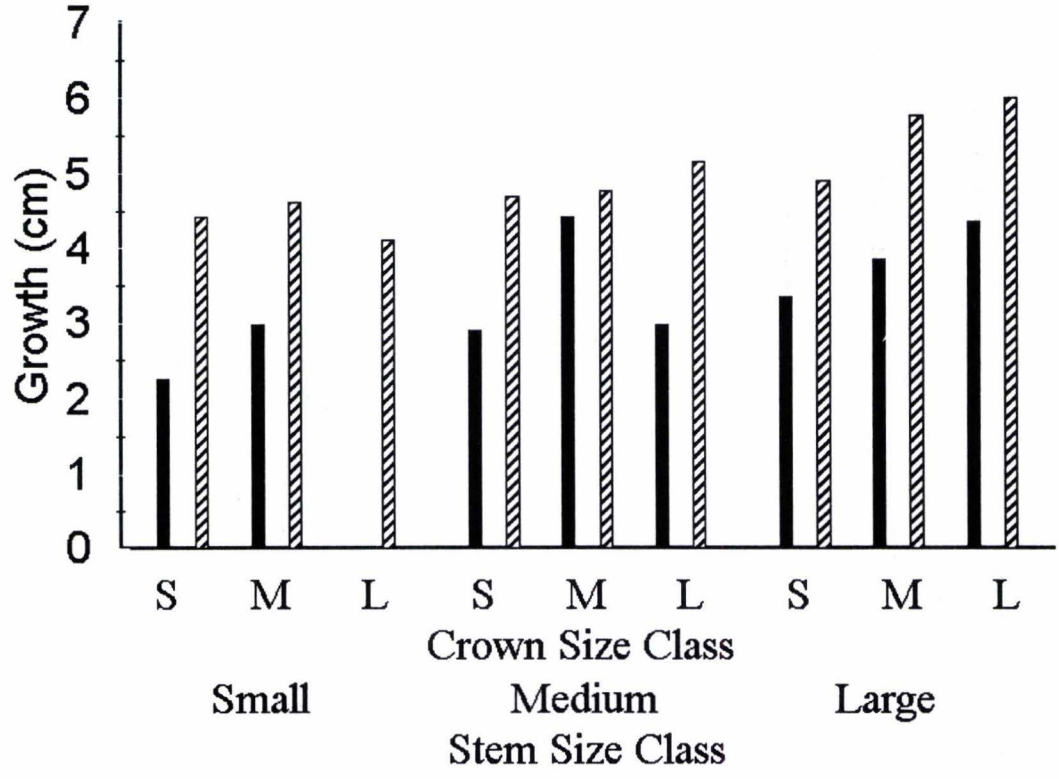

Figure 2.—Ten-year diameter growth by stem and crown classes. The solid bars represent the trees not released and the dashed bars represent the trees released.

on black walnut root systems (Biswell 1935, Perevertailo 1969, Yen *et al.* 1978) indicates that the horizontal root spread may be two to three times greater than the crown spread. However, the degree to which overlapping root systems are actually competing is not known.

Another possible explanation relates to the spacing of the trees. Steill (1978) showed that the lack of uniformity in the distribution of trees throughout an area affected diameter growth. Within-row crowding in this study would occur at CCF 66. Therefore, unless the trees could offset the within-row crowding by exploiting the between-row space, some reduction in growth might occur.

The rate at which diameter growth was reduced after the effects of crowding had begun increased only slightly as CCF increased. For example, if potential growth without competition were 1.0 cm, an increase in crowding from 100 to 110 CCF would reduce growth from 0.85 cm to 0.808 cm while an increase from 160 to 170 CCF would reduce growth from 0.587 cm to 0.542 cm. A similar pattern can be seen in the relation between foliage area and sapwood area for white and black oaks (*Quercus alba* L. and *Q. velutina* Lam.) (Rogers and Hinckley 1979), if one considers that foliar area changes in inverse proportion to CCF.

The response to release confirmed the conclusions of Clark (1967) and Phares and Williams (1971). The study trees were mainly codominants, with some dominants and a few intermediates (dominated). At least for these crown classes, the response to release appears to be consistent for all original stem size and crown size groups. The lack of any interactions among the three factors analyzed was surprising, as one might have expected less response from small trees with small crowns and perhaps the large trees with large crowns.

The literature on the effects of stand density on growth is voluminous (Smith 1962). Continued expansion of the literature since 1962 reflects both the importance and the complexity of thinning in forest management. Even for a single species, the number of possible thinning strategies is large because of the variation in original spacing: the timing, degrees, and types of thinning: and the desired end products.

Futhermore, an initial strategy may change during the rotation due to changes in external conditions and markets (Kirkland 1976). Therefore, integrating biological response data and modeling techniques (e.g., Chen *et al.* 1980) seems the best way to accommodate all the possible combinations of management objectives and biological situations.

For black walnut, two questions regarding the response to crowding still need to be addressed. First, is the response for uniformly spaced trees similar to that for the trees studied or is the onset of competition delayed? Second, do the trees selected for retention following thinning respond to the prethinning competition to the same degree as the average trees in the planting?

Since most retained trees will be selected from the largest, most vigorous trees in the stand (Funk *et al.* 1978), they could be less affected by a given level of competition than the average of all trees. Indeed, preliminary analysis using data from these study plots indicates a reduction in growth for the larger trees occurs at a CCF 10 units higher than for the average trees.

Once the above questions are answered, the response to crowding and to release can be incorporated into a thinning simulator (Funk *et al.* 1978). This biological model can then be used in conjunction with economic techniques (e.g., Ritters and Brodie 1984) to develop thinning strategies for various management-objective and biological-situation combinations for black walnut.

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IMPORTANCE OF SITE SELECTION FOR BLACK WALNUT PLANTINGS

Bob Chenoweth[1]

ABSTRACT.—Observations made from four black walnut plantations near the North Fork River in Vermilion County near Danville, Illinois are summarized. These plantations demonstrate the importance of proper site selection, benefits of pruning and thinning, and will be included in the 1998 annual meeting of the Walnut Council. Several are described in more detail in Black Walnut, a book published by Bob Chenoweth in 1995.

As part of my presentation, I would like to give you a preview of several plantings you will see on the field tour during the 1998 annual meeting of Walnut Council in Danville, Illinois to be hosted by the Illinois Chapter. These plantings for the field tour are located in Vermilion County approximately 100 miles south of Chicago. They offer an excellent opportunity to study different walnut sites in close proximity to each other, but producing very different results. In this area, the North Fork River flows through the Grand Prairie and along the west edge of Rossville, Illinois, before it turns east just south of Rossville and then south toward Danville and Lake Vermilion. Walnuts planted along the banks of this river thrive while those on the prairie are stunted or deformed.

In 1982, Richard Schlecht planted an equal mix of 740 Purdue #1 grafts and seedlings from Purdue #1 behind his Rossville home on the east bank and flood plain of the North Fork River. Seedlings were planted on 2.4 acres with 12 ft centers. Grass and weeds were controlled by spraying around the seedlings and mowing between the trees. In 1995, approximately one-third of the smaller and more crooked trees were removed leaving 475 trees with an average cost of about $17.00 per tree not counting his labor and land value.

Schlecht's plantation has made spectacular growth with many trees averaging about 6.5 in. in diameter at breast height (d.b.h.) in 1996. In general the trees from nuts of Purdue #1 grafts have outperformed the Purdue #1 grafts. All trees have been pruned to a height of about 12 ft and many have excellent form. Growth has been rapid, but the trees are competing for light and crown space. Many of the trees are putting on rapid height growth, but their crowns remain thin and puny. Additional pruning and thinning will be done.

Approximately 5 miles south of Rossville, Neil Andrews planted an acre of the Purdue #1 grafts on a heavy, black prairie soil approximately 2 miles west of the North Fork River. In addition to being planted on somewhat poorly drained soils, these trees are exposed to prairie winds. Most of the trees are stunted, deformed, and offer poor prospects of ever producing a quality log.

My experience with black walnut began in 1976 when we last lightly grazed a 20-acre pasture along the slope of the old river bank. Soils in the pasture were good sandy loams with ample moisture all year. More than 400 black walnut trees have naturally regenerated in the pasture. I tagged most of these trees at the base with white identification aluminum tags. Over the last 7 years I have pruned most to a height of about 15 ft. Most trees now have clear, straight stems and are growing very rapidly. I measured the d.b.h. in 1993 and 1996 and plan to measure them again in 1998 so that I will have 4 year growth data for the Walnut Council meeting. As I pruned and thinned this year, it was obvious to me that the growth increased the closer I got to

[1] Bob Chenoweth, Author and Walnut Grower, 606 Gulph Road, Wayne, PA 19087-1015. Summary of Landowner Show and Tell presentation at Fifth Black Walnut Symposium.

the lower, moist, rich soil near the river or when the trees had large, well-shaped crowns. The average d.b.h. is now close to 7 in.

Near the pasture planting, 22.6 acres were planted along the west bank of the North Fork River. This planting is a mix of black walnut, red oak, white oak, ash, tulip poplar, white pine, and European black alder. The trees have suffered from heavy grass and weed competition partially because herbicides were applied for only 2 years after establishment. The trees have also suffered from browsing by rabbits and deer, girdling by voles and mice, and terminal bud borers. In spite of these hardships, the trees close to the North Fork River are thriving and growing very rapidly. As the land rises toward the Grand Prairie, the walnut trees have grown more slowly and are more stunted. Conversely, the oaks show better survival and have grown much better than the walnut. Oak seem to do better than walnut in competition with brome grass, and seem to resist deer browse better, although they will require much pruning to produce clear stems.

I am thankful I planted a mixed plantation and included so many oaks. The clear lesson from my observations is that attempting to grow black walnut on land not suited to walnut is a big mistake. Walnuts will thrive best in the deep, rich, well-drained river bank soils. I'd leave the heavier, less well-drained prairie soil to the oaks. I am convinced that eventually I will have a hardwood forest of walnut on the lower ground near the river and oaks on the remainder.

My experiences in growing black walnut are described in more detail in Chapter 8 of my book titled Black Walnut published in 1995 by Sagamore Publishing Inc. The book also includes much historical information about the eastern black walnut and interviews with many growers and researchers. I still have a limited number of copies of Black Walnut that will be available from me for $30.00 (including postage and handling) until all the remaining copies are sold.

PRINCIPLES OF MANAGING FOR BLACK WALNUT IN MIXED HARDWOOD STANDS

John P. Slusher[1]

ABSTRACT.—My message can be summarized as manage the woodlot you already have before you begin establishing a new woodlot. Six things a landowner should know about black walnut management in mixed stands are discussed. These include where black walnut naturally grows, the composition of the woodlot, the importance of a good growing site, the importance of light, the importance of tree spacing, and the importance of tree size and quality.

My friend Larry Harper, tree farmer and editor of the Missouri Ruralist, has written an editorial titled "Only Old Men Plant Trees," which I personally find to be an intriguing observation. It's not entirely accurate - I plant trees, and I'm only in my sixties. However, it does reflect a certain general trend that I have observed over the years. Many reasons are given such as: atonement for past environmental sins; a last attempt at immortality; leaving something for future generations; a form of exercise more productive than jogging; are but a few of the many theories that have been given.

While it would appear that the "Supreme Being" has instilled in us this urge to procreate - it may be blinding us to a more productive use of our time - especially you folks who are older than I am. As a correlation to this theory, I might add that, in general, I have found being a grandparent is a whole lot easier, and more fun, than being a parent, even though you don't have as much direct control over the situation.

What does all this philosophy have to do with my paper? Not much, but I thought you should be made aware of these things. Actually, there is a message hidden in there. The message is: Before you begin establishing a new woodlot, manage the woodlot you already have. It may very well be a better use of your time since many of the mistakes you would have made have already been made and sorted out. Now you have a running start at being successful in your lifetime.

Bob Phares (1973) said it best in his paper "Managing Immature Trees For More High-Quality Logs and Related Products" at the Second Black Walnut Symposium held in Carbondale, Illinois. He said "much can be done with immature walnut trees to promote rapid growth of high-quality wood. Research and experience suggest that with proper care these immature trees can produce good seed crops in 10 to 12 years, 16-in. saw logs in 30 to 35 years and 20-in. veneer logs in 40 to 50 years from the time of planting on good sites. And by applying some of these same practices to established trees, it is not unreasonable to expect that growth and quality can be more than doubled in only a few years. Without intensive management, growth and yield of immature trees will be lower and rotations longer."

SIX THINGS THE LANDOWNER SHOULD KNOW ABOUT BLACK WALNUT MANAGEMENT IN MIXED STANDS

WHERE BLACK WALNUT NATURALLY GROWS

Eastern black walnut (*Juglans nigra* L.) generally is found in woodlands as scattered individual trees or in small groups mixed with a wide variety of other types of trees. In the central and northern part of its natural range, it frequently appears with white ash, basswood, yellow-poplar,

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black cherry, beech, sugar maple, red oak, and hickories. On the limestone soils in Kentucky, Tennessee and western Missouri, black walnut is often found growing with red cedar and honey locust. Other common associates in the southern, central, and western parts of its range include elm, hackberry, green ash, and box elder (Landt and Phares 1973).

Because of the wide variety of associated trees, each with its own requirements for growth and survival, no attempt will be made in this paper to address space requirements or management techniques for all combinations of trees. Rather, the management recommendations will relate to individual walnut trees or small groups of walnut within mixed stands. Recommendations for the remainder of the species or for the overall woodland should be given by professional foresters, and it is highly recommended the woodland owner seek such professional assistance.

THE COMPOSITION OF THE WOODLOT

The composition of the woodlot is best determined by an inventory. I strongly recommend the assistance of a professional forester in this process. An inventory is simply the gathering of the data necessary to evaluate the woodland's potential and opportunities. Then a management plan may be developed to define objectives and how to reach them through a series of cultural practices. Once landowners are aware of what currently exists on their land and what the financial and cultural alternatives are, they may begin to implement all or a part of the plan. Accurate records should be kept at all stages to evaluate financial decisions and also take full advantage of the long term capital gains benefits of timber investment. Accurate records of growth will also help determine how much timber can be harvested without depleting the base from which the growth is made.

THE IMPORTANCE OF A GOOD GROWING SITE

Black walnut is very sensitive to soil conditions. It grows best on deep, well-drained, nearly neutral soils which are fertile and moist, but not wet. The most favorable sites are in coves, along narrow streams, and on north and east-facing slopes. It seems to do especially well on limestone-derived soils. Black walnut does not thrive on wet bottomlands, or on sandy dry ridges or slopes, or soils which are underlain by shallow bedrock, gravel, or hard-pans which limit root penetration. Good internal drainage and soil aeration are a "must" for best growth by this species (Landt and Phares 1973).

Under these optimum kinds of conditions black walnut is one of the more rapid-growing hardwoods. On good sites, young trees may grow 3 or 4 ft in height per year and in 20 years may attain heights of 50 to 60 ft with diameters of 6 to 12 in.

The quality of a site is reflected in its "site index rating." "Site index" is the number assigned which reflects how tall a tree will grow in a specified number of years (usually 50). A walnut site index of 80 indicates that particular location will grow a walnut tree to 80 ft of height in 50 years when in close competition with other hardwood trees. The higher the site index number the better the site.

Good walnut growing sites produce more volume of wood per acre than poor growing sites even where the same number of trees are involved. Good sites also produce a given volume of wood in a shorter period of time than poor sites. Brinkman (1966) provides yield data in board-feet-per-acre from various sites (Table 1). The bold-print data in the table reveals that walnut growing on a site with an index of 40 would require 65 years to produce 870 board feet of wood, while a site index of 80 could produce the same amount in 25 years.

The darkened numbers in the 75-year-age line indicates that in 75 years the site index 40 location would produce only 1,250 board feet of wood per acre, while in the same time span the site index 80 would produce 18,250 board feet. The importance of a good growing site can not be over emphasized because no amount of fertilizer or irrigation or genetic improvement can economically offset the disadvantages of a poor site.

THE IMPORTANCE OF LIGHT

Another important characteristic of black walnut is that it is intolerant of shade. It requires nearly full sunlight to survive and grow. In mixed forest stands walnut must be in a dominant or co-dominant position with other trees to maintain itself. Its intolerance to shade is an important factor to consider in several stages of management. If woodland owners are trying to replant

Table 1.—Yields in board feet per acre of black walnut plantations in the north central region by age and site index[1] (Trees planted at a 10-foot spacing)

Age (years)	Site index				
	40	50	60	70	80
20	—	—	—	—	100
25	—	—	110	380	**900**
30	—	—	360	1,000	2,200
35	—	200	810	1,930	3,760
40	—	400	1,400	3,300	5,670
45	170	780	2,160	5,100	7,860
50	250	1,200	3,100	6,500	9,820
55	400	1,700	4,150	8,010	11,750
60	630	2,250	5,210	9,380	13,150
65	**870**	2,800	6,230	10,060	14,400
70	1,060	3,350	7,170	11,620	15,460
75	**1,250**	3,800	8,000	12,550	**18,250**

[1]Volume in board feet per acre (Scribner Rule) of trees 10 in. d.b.h. and larger to an 8-in. top diameter inside bark.

openings created in a natural stand, they must be aware that without an opening at least 1/3- to 1/2-acre in size a walnut planting will almost always result in failure. Even then, several years of controlling competing vegetation is necessary. Sander (1966) reported that in openings less than about 1/2-acre size, growth of all reproduction is generally retarded in a border zone that may comprise up to 40% of the area in the opening.

THE IMPORTANCE OF SPACING

In general, the goal of timber management is to keep the proper number of healthy desirable trees growing at their maximum rate at a given point in the age of the stand of trees. An acre is capable of supporting more young (small) trees than old (big) trees. For each tree to grow at its maximum rate, it must have access to all the nutrients, water, and sunlight it needs. As the competition for these factors increases, growth slows and stresses set in, reducing the health and capability of the tree to maximize growth. Competition results in natural mortality and fewer trees competing for the elements of survival. The manager tries to guide this process by controlling the spacing and species selection.

In older, mixed-species woodlands, where spacing has not been previously controlled, one of the first tasks for a landowner growing high-value species, is to select the best trees for concentrating future growth. The sooner these potential "crop-trees" can be selected and favored with cultural treatments the sooner the return on investment will occur.

Early growth characteristics often provide a good clue to future development (Phares 1973). In older woodlands, the size of the tree crown and its relative position in the main canopy are good indicators of growth potential. Where a choice is possible, dominant trees should be favored over overtopped trees if other factors are equal.

The trees selected as the "crop trees" must have adequate growing space in order to maintain rapid growth. Any trees in competition with less desirable trees must be released before they become deformed or weakened to the point they are unable to respond properly to release. Competing trees may be harvested for products, simply girdled, or injected with appropriate herbicides. Care must be used to apply herbicides with strict attention to instructions on the label. Failure to do so can cause injury to the applicator, damage to non-targeted trees, or damage to the environment. Even when properly applied, injury to surrounding vegetation can occur through transport of the chemical by grafted roots, soil movement, leaching of chemicals, or other methods.

There are many rules of thumb, or formulas, used to roughly determine proper tree spacing. One such rule suggests that enough trees should be removed each time a thinning is made to allow the trees to grow about 4 in. in diameter before the tops again become too crowded.

A second rule-of-thumb builds on the first by developing a constant factor which specifies a given distance that it takes for trees to grow 4 in. in diameter before the crowns again touch. It states that, following a thinning, the space between two remaining trees stems should equal the average of their diameters (expressed as feet instead of inches), plus a constant factor of 16 ft.

Example: After thinning, if two remaining crop trees are 6 in. and 10 in. in d.b.h., their average d.b.h. would be 6 + 10 ÷ 2 = 8 in. Substituting feet for inches and adding a factor of 16 ft would mean the trees should be spaced 8 ft + 16 ft or 24 ft apart to allow for 4 in. of future diameter growth. When they average 12 in. in diameter the thinning process would need to be repeated.

Stocking levels and spacings recommended by (Phares 1973), based on studies by Krajicek, for high-quality veneer logs and good nut production on good sites are shown in Table 2. The example rule-of-thumb numbers are in bold-print in the table. Obviously, rule-of-thumb figures will not always correspond exactly to the spacings in the table.

It should be noted that when a major emphasis is placed on nut production, additional trees must be removed to further maximize tree crown development. However, widely spaced trees tend to retain their lower branches for a longer time period and may require more lateral branch pruning. Also, trees that are drastically released from competition will often develop sprouts from dormant buds along the trunk (commonly called "epicormic branches" or "water sprouts"). These sprouts must also be removed before they become limbs that will downgrade log quality.

Ponder and Schlesinger (1988) suggest in the Walnut Notes that when releasing walnut in natural stands for it, "To be effective, release should increase the growing space available to the tree on at least three sides. As a general rule, there should be at least 10 ft between the

Table 2.—Tentative stocking guidelines for growing high-quality black walnut on good sites based on the assumption that crop trees will grow 4 in. in diameter before they again need to be thinned or released

Average stand d.b.h. (in.)	Stocking spacing when crowns begin to touch[1]		Recommended stocking and spacing for thinning or releasing for different product objectives			
			Veneer logs		Veneer logs and nuts	
	Trees per acre	Spacing between trees	Trees per acre	Spacing between trees	Trees per acre	Spacing between trees
	Number	*Feet*	*Number*	*Feet*	*Number*	*Feet*
2	797	7	265	13	225	14
4	380	11	175	16	150	17
6	223	14	125	19	105	20
8	147	17	90	22	80	23
10	104	20	70	25	60	27
12	78	**24**	55	28	50	30
14	60	27	45	31	40	33
16	48	30	40	33	35	35
18	39	33	35	35	30	38
20	32	37	30	38	25	42
22	27	40	—	—	—	—
24	23	43	—	—	—	—

[1]Obtained from the equation (Krajicek 1966): crown width (ft) = 1.993 x d.b.h. (in.) + 4.873.

walnut crowns after release. Additional treatments will be required periodically as the walnut crown grows out into available space."

These rules-of-thumb are general in nature and apply primarily to spacings related to black walnut. The table itself relates to walnut plantations. To a degree, it may be applied to individual walnut tree release in mixed stands or to solid blocks of walnut trees within a mixed-species woodland. Other species of trees have their own optimum stocking levels and growing space needs.

It is also important to consider the quality of competing trees when thinning the stand. For instance, when a walnut of low future value is in competition with a potential high-value tree of another species or a desirable den tree, etc., the walnut should be removed to favor the other tree. Because of the many judgments that must be made in thinning a stand of trees it is usually advisable for the landowner to seek professional forestry assistance in determining how to develop and implement cultural practices for the individual woodland situation.

Walnut growers interested in more precise spacing information based on Crown Competition Factor (CCF) should consult the Manager's Handbook For Black Walnut (Schlesinger and Funk 1977), the Walnut Notes 3.03, 3.04, and 3.05 (Schlesinger 1988a, 1988b; Schlesinger and Ponder 1988), or the paper in this proceedings (Schlesinger 1997).

THE IMPORTANCE OF TREE SIZE AND QUALITY

A basic understanding is needed by the landowners about the importance of developing the quality of log if they are to command a premium price at harvest time. The price paid by a buyer for a tree standing in the woods (its stumpage value) is primarily influenced by its location, size, quality and the current market value of the products it will yield. If we assume that tree location and market value are factors that the landowner cannot change, then the only things the owner can do to increase his total return from that tree are those related to size and quality at market time. He can of course, through management, reduce the length of time it takes to get to market size. It should also be noted that, usually size and quality are somewhat related because a smaller tree generally has more natural defects and a higher bark and slab percentage than a large tree. Assuming trees to be similar, a tree measured by the Doyle tree scale indicates a tree 14 in. in diameter at breast height (d.b.h.) with a 16 ft merchantable height would contain 48 bd ft of lumber. A tree double that diameter (28 in. in d.b.h.) would contain 317 bd ft in the same 16 ft log length. Doubling the tree's diameter therefore increased its volume more than six times. This type of volume increase would hold true for oak or any other species.

Quality of the wood affects the price paid for each board foot. A tree that will produce only low-grade lumber will bring a low price per board foot on the stump. The same tree, if it contained wood that was capable of producing veneer, might bring ten to a hundred times the price for the same board foot.

In our earlier example, by doubling the size of the tree the landowner increased its volume by six times. Then by making sure the quality of the stem produced veneer worth many times as much as low grade lumber, he increased the total value of the tree greatly. That is the reason foresters try to find the best potential trees to grow to a larger size. Table 3 illustrates how the combined increase in volume with increased value per unit of measure might affect the individual tree's value.

CLEAR-STEM PRUNING

A cultural practice which can greatly increase the future value of young walnut trees is "clear-stem" or "side-stem" pruning. The objective is to remove lateral branches to allow the formation of clear, defect-free wood in the lower logs of the tree. Clear, knot-free, logs are necessary for the higher value products such as veneer or the highest grades of lumber. By the time a tree has reached 8 to 12 in. in diameter, it is often too late for effective pruning because there will not be enough clear wood produced over the pruning wounds to greatly increase log value. Limbs should be removed before they reach 2 in. in diameter to keep the wound from being too large for proper closing. A neat, clean cut should be made, preferably with a pruning saw. Only those trees likely to be selected as crop trees need to be pruned. There is not reason to sustain pruning

Table 3.—Walnut "crop tree" value at different sizes (using Doyle tree scale [FC 78])

D.B.H. (in.)	No. of 16 ft logs	Board feet	$/MBF* (stumpage)	Tree value (dollars)
14	1.0	48	.25	12.00
18	1.0	100	.50	50.00
22	1.5	234	1.00	234.00
26	2.0	459	1.50	688.50
30	2.0	658	2.00	1,316.00

*The prices used above are illustrative only and should not be used to evaluate the worth of individual trees or woodlands.

costs on trees which will obviously be removed from the stand before the benefits of pruning can be realized. Detailed information on proper pruning is available in "Thinning and Pruning for Quality" (Schlesinger 1989).

How high to eventually prune depends on the product objective and on the cost and difficulty of pruning. Foresters generally recommend a minimum of 9 ft of clear log to meet minimum veneer standards. When nut production is a goal, a fairly large crown is needed and therefore the butt log may be the only one pruned. Remember, some follow-up pruning will be needed to remove any epicormic sprouts that develop later.

PROTECTION

Protection from fire and grazing are the two primary needs for most hardwood woodlands. The private woodland owner should contact his state forester for information about fire protection assistance. Fencing may be necessary where livestock have access to the woodland in order to prevent excessive damage to trees and young reproduction. Insect and disease problems should be monitored to avoid problems developing into epidemic proportions but, except for sanitation cuttings controls, are seldom warranted in mixed hardwood stands.

ASSISTANCE AVAILABLE

Remember, there is a great deal of good information and technical assistance available through the Walnut Council; the USDA Forest Service; state foresters; schools of forestry at universities and Cooperative Extension; Natural Resource Conservation Service and from Farm Services offices in each state. Consulting foresters, private industries and others can also advise landowners and provide services for various management or marketing needs.

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PUBLICITY GUIDE FOR TREE FARM AND WALNUT PLANTATION TOURS

Connie Johnson and John Johnson[1]

ABSTRACT.—The guide provides an outline for planning field tours of our tree farm and walnut plantations, what materials to prepare, determining your objective and who the audience should be, and scheduling of the field tour.

I. Know what you want to show before you start! Plan a tour of your tree farm or walnut plantation. Decide what it is you want to show—what are the most interesting features.
   A. Organize the content of the tour striving for variety. Try to cover the areas of tree farm emphasis—wood, water, recreation, and wildlife.
      1. Introduce yourself and welcome your visitors.
      2. Tell the history of your farm and your ownership story.
      3. Give an overview of the coming tour and talk about your rules.
      4. Plan the tour in detail, especially if you are new at the tour guide role. You can always leave out material during the tour, but it's hard to add material.
   B. Decide on the mode of transportation. Will it be the visitor's cars in caravan, your wagon pulled by a tractor, a walking tour?
   C. Figure out a route that connects what you want to show. Usually a circle is best. Next best, a trail with a turn-around at the end. Avoid overlapping sections along the route.
   D. Design permanent signs to mark your most interesting features or "stops."
      1. Local highway departments are a good source of old real estate signs that can be painted and are easily installed the day before scheduled tours.
      2. Always date the signs. Most of us quickly forget what year different cultural practices were carried out. For example, Timber Sale 1991 or Planted 1993.
   E. Make separate enrichment folders for each stop. Keeping everything related to each stop together will make it easier to answer questions.
   F. Plan a enjoyable, positive ending to your tour.
      1. Have handouts ready to send home with visitors. Sources of materials include local extension offices, departments of natural resources, and forestry organizations.
      2. Close with a hospitality/question/discussion session.
         a. Keep a supply of disposable cups on hand. Plan to serve ice tea or ice water in the summer. In the winter serve coffee or hot chocolate.
         b. Keep a couple quick nut cookie recipes handy or a jar of cookies in the freezer.

II. Make a map to your farm clearly identifying roads and local landmarks.
   A. Start with a regional or county map. Mark route plainly using stick on arrows, etc.
   B. Add written directions at the bottom of the map.
   C. Make photocopies of the map at a local copy shop.

[1] Connie Johnson and John Johnson, Horse Creek Farm, #1 Horse Creek Road, Route #1, Box 178-M, Galena, MO 65656. Outline from Landowner Show and Tell Presentation at the Fifth Black Walnut Symposium

III. Develop a list of names, addresses, and telephone numbers of people you would like to know about your tree farm or walnut plantation. Be sure to keep your list up to date.
   A. Include media contacts, especially editors and correspondents of farm news for newspapers, TV, and radio stations at the local, county, and closest large city.
   B. Include political contacts such as county officials, State Representatives and Senators, and U.S. Congressman and Senators.
   C. Include members of Environmental and Nature Clubs. Check local newspaper's calendar of events section for names.
   D. Include school and youth clubs
      1. Contact local 4-H, FFA, and Scout leaders.
      2. Contact local school administrators. Also get involved with local PTA and put your name and address on the reference page of their guide book.
   E. Include farm visitors. These include family, neighbors, other Tree Farm and Walnut Council members, and everyone who has already visited the farm.

IV. Make a publicity plan and schedule for planned tours.
   A. Decide what you want to show, the best time of the year, and who is the audience.
   B. Schedule mailing invitations and publicity releases.
      1. Invitations should be mailed 30 days in advance of the tour.
      2. Publicity releases should be mailed 3 weeks in advance of the tour. Ask for a guide on writing publicity releases for various media.
      3. Design your own stationary for correspondence.
         a. Design your own letterhead with your own logo or member forestry organizations, your name, address, and telephone numbers.
         b. Design a footer that says something about your expertise and qualifications.
         c. Have 250 copies run off on good paper when you get your map copied.
   C. Prepare for surprises. As word about your farm and your hospitality get around you will be contacted for interviews and short stories.
      1. Collect forestry facts and figures and keep them handy. Many organizations have fact sheets showing the importance of forestry to the economy and environment.
      2. Attend tours hosted by others to get some ideas for your own. Groups like Hammons Products Company are masters as putting on good field tours.
      3. If asked to do an interview, discuss what you will be asked and decide how you will respond before starting to record. If you don't want to comment, tell the interviewer before you start recording.
      4. Have a plan for dealing with spur of the minute interviews.
         a. It is easy to panic if you get an interview call and the media crew is on its way.
         b. Out in the field talking about trees is always a winner!

ESTABLISHMENT AND EARLY CULTURE OF WALNUT PLANTATIONS — A 37 YEAR EXPERIENCE

Robert D. Burke and Stephen G. Pennington[1]

ABSTRACT.—We describe our experiences and recommendations after 37 years of working with black walnut in plantations and natural stands as forest managers, as log buyers for saw and veneer mills, and as cooperators on conducting research on black walnut in plantations and natural stands. The subjects covered are the needs of the wood industry and benefits of woods-grown trees verses plantation-grown trees. We give our assessment of how successful we have been in developing the techniques to produce quality wood through research and demonstration.

INTRODUCTION

Black walnut (*Juglans nigra* L.) has always been a favorite eastern United States hardwood. Landowners and potential landowners have developed an appreciable interest in establishing and caring for plantations of walnut for future income to farming operations or family. Foresters, researchers, and landowners have developed walnut plantation management techniques sufficiently so prospective growers can now proceed with plantation development in a confident manner using these techniques, feeling comfortable that attention to recommendations will produce quality wood in plantations and natural stands.

Reasons for establishing walnut plantations include the expectation of an eventual profitable return. In a recent study of alternatives under the Conservation Reserve Farm Programs, planting black walnut on suitable sites emerged as a financially attractive investment. In another economic comparison of Eastern timber investments, black walnut plantation investments had one of the highest net present worth. Forest investments can have additional benefits in regard to risk diversification and inflation protection, but growing walnut is a long-term activity and a part of the long-term portions of investment portfolios. Since it is an investment carried for many years, it is logical that establishment and early work be done correctly and efficiently.

This article emphasizes attainment of quality in the plantation from the beginning by giving attention to certain minimum establishment and care principles. Simply stated, this article discusses how to prepare the site, plant the trees, and start them growing well. These processes can be enjoyable and even though financial investment may have been the initial reason for becoming involved, many growers soon discover that working in their walnut plantations can also have recreational value.

SITE SELECTION

The first point is that site selection is the most important step in establishing a walnut plantation. The second point is to recognize that while most walnut are planted in open fields, growers should not overlook the possibility of planting in forest situations. Planting walnut in forest openings is quickly becoming recognized as a good technique for growers to use. The natural hardwood forests within the central U.S. are themselves a valuable resource, and many landowners apply proper management to these forests. A part of management is harvesting, and often harvesting creates small openings in the forest wherein all large trees have been removed. If an opening is 2 to 4 (or more) acres in size and is of the correct soil type, it may be suitable for

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planting walnut seedlings. An opening of this size would be of sufficient size so the surrounding large trees would not grow out over it and enough sunlight could reach the forest floor for enough years to allow walnut tree establishment. With the leaf and duff layer and forest organisms already present, natural wood sites can often provide good walnut growth. Many growers are discovering this as a good way to increase the number of walnut trees on their landholdings.

Whatever the site that is eventually considered (whether it be field, forest opening, barn lot, or backyard), the prospective walnut grower definitely should seek out detailed soils and site information before investing. Good technical soil and site information is available and should be used. Make sure the site is capable of supporting quality walnut growth. Utilize the services of a forester or soil scientist to make on-site investigations, if in doubt.

SITE PREPARATION

After the plantation site is selected, but before it is planted, several things may be done to prepare the site. Pre-plant site preparation will promote better growth of the walnut and make future management of the plantation easier. Site preparation usually involves doing something to or with the vegetation that is already growing on the site. This may be accomplished by using site-preparation chemicals or by using farm machinery around newly-planted trees.

A common example of site preparation needs is a field that has been used for forage and has a grass sod established. Sod can be extremely detrimental to good walnut growth, and its removal can be accomplished by mechanical means such as plowing or repeated disking. The chemical means would involve spraying with a broad-spectrum herbicide such as glyphosate. Particularly heavy sods may need both methods. If the site has a crop residue, such as corn stubble or common annual farm weeds, simple disking or mowing may be adequate site preparation. Disked or mowed surface facilitates subsequent plantation layout and planting.

Site preparation can go one step beyond simple elimination of undesirable vegetation with establishment of a desirable ground cover vegetation that will remain on the site during the first few years of walnut tree growth. Various legume mixtures like hairy vetch and lespedeza have been tried and recommended for increasing walnut growth, suppressing other weeds, and providing ground mulch. Sowing legumes with a drill press before tree planting requires less seed and is usually more convenient than broadcast seedling. Soil amendments, like lime, for establishing the walnut trees and ground covers are sometimes needed. It is easier to apply these during site preparation than attempting application after the trees are planted.

If the site selected for planting is an opening created via harvesting in an existing woodland rather than an open field site, work specific to that situation is needed. Control of existing vegetation is the primary site-preparation task. Within the opening, scattered large brush, damaged trees, trees of undesirable species, and snags remaining after logging should be deadened or felled, and the stumps treated with herbicide to prevent resprouting. When a forest floor in a natural hardwood opening is exposed to sunlight, a dense flush of germination and seedling growth usually occurs in the first year. Composition of this growth should be examined. If walnut is a significant component, planting would not be necessary. Opening management would involve treatment to bring the walnut through the first few years as the dominant trees. If walnut is not a viable component in the new growth, supplemental planting should then be considered. One technique is to eliminate the first natural flush of new growth with herbicide, follow-up with walnut planting the following spring, and release the walnut seedlings as needed in subsequent years.

These are basics in site preparation utilizing some common examples. For unusual or particularly difficult site and vegetation situations (such as fields already overgrown with brush or situations with noxious weeds), checking with a forester can yield information on efficient procedures. For growers wishing to be more involved, the time of site preparation can also be a time to take care of road building, fencing, ditching, or other work that may facilitate management of the plantation in future years.

SEEDLINGS

The growers have four opportunities for assuring adequate genetic and morphological make-up

(quality) of the plantation during the establishment and early care of walnut plantations. These are: (1) choice of seed source; (2) acquisition of genetically improved seedlings; (3) sorting or grading of seedlings; and (4) spacing between seedlings and subsequent thinning. Three of the four opportunities occur in the seedling procurement phase.

Seed and seedling source are important. It is recommended that the grower be involved enough to assure that the seed the nursery used to produce the seedlings is suitable for your location. Genetics research has given ample guidelines on seed source. The local source is the safest; however sources within 100 to 200 miles south of the planting site will provide faster growth with minimal risks from winter kill. Seed collected from "unknown places" is deemed unsafe. Pay attention to seed source, and avoid severe problems later in the life of the plantation. Nursery managers are careful about seed source and can normally furnish the proper information.

The majority of states in the walnut range now have plant breeding programs in operation aimed at the eventual production of genetically improved walnut seedlings. Most of these programs are in the early stages. Improved material may not be available in your area, but it may be useful to check around before purchasing seedlings to plant.

After acquiring seedlings, but before planting, many growers take the third opportunity for improving the quality of the trees by personally sorting for the best seedlings. Some nurseries do seedling sorting (grading) before shipment, making this step unnecessary unless the grower wishes to further sort to a higher standard. During sorting, seedlings that are deformed or damaged are discarded. All seedlings showing evidence such as root rot or insect infestation are discarded and preferably destroyed by incineration. A "good" black walnut seedling for planting would be healthy in appearance, have a single stem, and have a well-developed root system possessing several (7 to 9) smaller lateral roots coming from the main tap root(s). A high percentage of the seedlings planted should possess these standards.

It is important to point out that there are other ways to establish a plantation. Direct seeding, planting the nuts rather than seedlings, is an alternative, but several problems have caused this method to fall into disfavor. Lack of uniform germination is a problem, and often two or three seeds are planted per space to insure at least one seedling per planting spot. If all seed germinate, thinning to one tree per space is required. A big problem with direct seeding is depredation of seeds by squirrels.

Container-grown seedlings and tubelings have been tried, but the difficulties in handling and transporting these seedlings over a very long distance can be a problem. Neither survival nor growth improved over bare-root seedlings. Some growers have tried planting trees larger than 1-year-old seedlings, but the expense involved quickly becomes excessive. Through past experimentation, 1-year-old (1-0) seedlings of 8 in. to 2 ft or so in height have proven to be highly practical for planting, because they are inexpensive to purchase. Most reforestation nurseries are now producing quality bare-root 1-0 walnut seedlings.

PLANTING

As mentioned previously, another chance to improve the quality of the walnut plantation is through close spacing of the trees and the subsequent thinning. In laying out the plantation, a close spacing is selected. Usually spacings are 10 x 10 ft, 10 x 12 ft, or 12 x 12 ft (100 to 150 square feet of area per walnut tree). The final choice within this range can be selected by the grower to accommodate practical considerations like width of mowers and sprayers. This spacing results in 300 to 450 trees per acre. Later, as the trees attain sawlog size, the site can accommodate only 50 to 100 trees per acre. During the thinning process, the grower selects poorer quality trees for removal, leaving the ones demonstrating superior inherent abilities for growth, straightness, form, and vigor. While in the plantation, the poorer trees have served to train the better trees. Eventually even some good trees must be thinned to provide adequate growing space for the crop trees. Research in tree improvement is progressing, and if grafted seedlings or improved seedlings of known genetic superiority are available, a wider spacing might be used.

The grower should decide before planting what the primary objective is for the plantation—nut production or timber production. In most cases, both cannot be the main goal. Nut production requires wider spacing for a better nut crop on shorter bole trees. Shorter bole trees produce less high-priced veneer than the taller timber type. A timber objective produces more veneer type trees due to the closer spacing, but smaller crowns produce a very small nut crop. In the future, after the plantation is thinned and larger crowns have developed on crop-trees, a bigger nut crop should be produced. If the grower wants both, a compromise must be made.

Experience has shown that the establishment phase (i.e., spacing, ground cover, and interplanting) is critical to developing quality timber-type walnut trees. Close spacing using interplanted species can help force the walnut to heights of 40 to 50 ft and a veneer-type stem. Wide spacing produces a short boled orchard-type tree and may reduce the potential for producing high value logs. If a grower has several acres of land for tree planting, he has a few alternatives for a goal. First, if nut production is the goal, the field could be planted on a wide spacing, but with reduced potential for timber production.

Second, if row crops and nut production are the goal, the field could be planted on a wide spacing, but again with reduced potential for timber production. If yearly income is desired, plant one half the field to row crops and the other half to walnut for timber production. Experience has shown the added cultural costs (pruning and weed control) and the reduced quality of open grown walnut trees are a big sacrifice in return for a few years of row crop income. Open grown trees produce large limbs due to the lack of shading. These limbs reach over the cultivated rows reducing the crop area each year. These large crowned are fine for nut production, but a short-boled open grown tree will produce lower quality veneer logs.

Finally, if timber production is the goal, the field could be planted on a close spacing to walnut — using interplanted species. Initially there would be little nut production. Eventually after the planting has been thinned and larger crowns are formed, more nuts would be produced.

Extreme wide spacing of 20 x 20 ft or wider have been tried. The other extreme is a close spacing of 5 x 5 ft. The theory with such ultra close spacing is that a large number of trees per acre allows more thinning for genetic gain and a greater forcing of straight upward stem growth. We are unsure if pure stands of walnut will produce walnut with the quality found in deep woods grown walnut trees. The mix of other species (interplanting) produces a more woods-like condition. With mixed plantings, the combination of wind protection, shading of the bole, and shading of the site where the walnut is growing helps retain moisture, thus creating a favorable environment of the walnut.

Agroforestry plantings (wherein grain or forage crops are grown between walnut rows for the first few years) and combination crops (for instance, planting ornamental conifers between walnut rows and later selling the conifers as ball and burlap stock or Christmas trees) are other methods being used. While all these (and others) are viable systems and are in use, it should be realized that they require more intensive management. Unless it is certain that this added activity will indeed be done, the grower should stay with the mainstream, standard recommendation of 100 to 150 square feet per walnut tree.

The guiding principle involved in the actual planting of the walnut seedlings has to do with expense. Viewing walnut plantations as a long-term financial investment, costs at the beginning are carried over the life of the plantation, and smaller costs are easier to carry over a long financial term. One-year-old seedlings are inexpensive and easy to plant. Planting methods have been developed to decrease planting costs. Seedlings can be placed by machine planters especially developed for reforestation. The ideal machines will have a deep (10-12 in.) and wide (4 in.) planting shoe to accommodate the large tap root of walnut. They will also have an arch tail tall enough (or other suitable design) to plant the seedlings without bending them over and possibly breaking off the buds. Machines plant quickly and should be considered for large jobs.

Hand-planting is usually done with a special tool, the tree-planting bar (or dibble), available by mail order from firms offering forestry supplies. The bar has a bit which is pushed into the ground,

creating a slit to accept the seedling roots. The bit is then pushed in to the ground behind the seedling and pulled back, then pushed forward to firm the soil around the roots. Care must be taken not to leave air pockets. A seedling can be planted quickly with a good bar. Hand planting is appropriate on smaller jobs or on rough terrain where the machine cannot go. Standard common-sense procedures for handling live plants apply, including keeping seedling roots moist and getting all the roots in the planting hole, pointing down and minimally tangled.

Tap roots should be pruned to 8 to10 in., and long lateral roots should be pruned to 2 to 4 in. to prevent the jamming of roots in a hole too small to accommodate them. The root collar (where the seedling root and stem meet) may be examined to see where the soil level was in the nursery. Seedlings should be planted at least that deep, preferably one-half inch deeper than the root collar or soil line in the nursery.

INTERPLANTING

Few areas of research have yielded more interesting and useful information than walnut interplantings. Researchers and growers have combined energies for years to identify species to plant among walnut trees in the plantation to serve as nurse trees and/or to supply factors that improve walnut growth and quality.

The advantages of interplanting may, in part, be explained by the fact that the presence of other tree and shrub species help attain a crown cover condition in the plantation sooner. Walnut by itself does not always give enough shade to suppress grasses and agricultural weeds. The interplanted species can help supply that shade, and walnut growth will often increase. Because walnut is a shade intolerant species, it will make every effort to reach for the sunlight. This trait makes it ideal for close spacing to force walnut height growth.

European black alder (*Alnus glutinosa* L.) was discovered early as a good interplanted species and is still used. A row of alder can be planted between each row of walnut or alder can be planted alternately with in each row of walnut. Alder can force the walnut to heights of 30 to 40 ft or more. If the walnut is planted on a 10 x 10 ft spacing, alder or other interplanted species can be planted between each walnut within the row producing a 5 x 10 ft spacing in the plantation. After 25 years of experience with this interplanting spacing, the results have been very good. The tree-like form of alder provides shading, wind protection, and supplies nitrogen to the walnut. This dense growth helps create a woods-like condition, which is favorable for good form and growth of the walnut. Alder begins to die in about 10 years due to the juglone produced by the walnut. Little or no sprouting of alder will occur.

Autumn olive (*Eleagnus umbellata* Thunb.) had emerged from grower trials as an interplanted species that forces the greatest early growth in walnut. Autumn olive fixes nitrogen, which the walnut can utilize for added height and diameter growth. The presence of nitrogen is evident by the deep green color of the leaves. Since autumn olive is more of a bush than a tree, the benefit of forcing the height of the walnut only occurs for a few years. On average, autumn olive will top out at about 10 to 20 ft in height. The fixing of nitrogen continues for several years after the autumn olive begins declining. After 10 years, the autumn olive is over-topped by the walnut and begins to die. A major disadvantage of autumn olive is that it can be spread by birds eating the red berries. In some northeastern states, it is considered a noxious weed.

White pine (*Pinus strobus* L.) is recognized as an excellent interplanted species and is being used in plantation in regions where it is a suitable species to plant. White pine does not fix nitrogen like autumn olive or alder does, but white pine does provide shade, training, and year round wind protection. Moisture retention is good under pines, and needle fall can quickly build on the ground, suppressing weeds and creating a forest-like condition on the soil. These features can help eliminate herbicide treatment and mowing after a few years because the white pine grows very full and tall. In most instances, the white pine will eventually be weakened and/or killed by the juglone from the walnuts. This usually occurs about the time that they should be thinned anyway. With white pine we have had to do less side pruning (due to the many branches of the white pine shading the stems) and less weed control after the initial few years (due to needle fall choking out weed and grass competition). In addition, the slightly higher growth rates for white pine help force walnut height growth.

In summary, we should point out that a wide range of species can be used, or combinations, or none at all, depending upon the grower's wishes. Many landowners are growing walnut in pure stands, controlling weeds completely with herbicides, and getting excellent growth. On the other extreme, mixed plantings have emerged as practical in many situations. For instance, a typical field selected to become a walnut plantation may be composed predominately of walnut soils but mixed with area of soils marginal for walnut or questionable as to suitability for walnut. A mixed planting on those marginal soils could be advisable. It could be a mixture of walnut, oak, ash, tulipwood, or cherry and interplanted shrub species within the rows with every other row, or every third row of white pine. Within the first few years of the plantation, the species most suitable for the questionable soil would become apparent. Subsequent management would then favor those species if these species can also produce valuable wood. Interplanting procedure may be a topic on which the grower will want the advice of a forester along with an analysis of soils and other factors in order to arrive at the final decision.

Much had been learned about the benefits of interplanting. Research has shown that much of the benefit is the result of moving the plantation toward a woods-like condition with soil properties similar to productive timber sites. Within this woods-like condition there is wind protection, moderation of temperature extremes, leaf and duff build-up, higher soil organic matter content, reduced competition from ground vegetation, increased water holding, and improved soil porosity and tilth. This results in improved growth and quality of the black walnut if compatible tree or shrub species are selected.

FERTILIZATION

Fertilization of newly established walnut plantings has not proven to be beneficial, especially if proper soils have been selected. Experience has shown in most cases that fertilizers depress seedling growth by stimulating competing weed growth. If the grass and weed competition is controlled, there is an increase in walnut growth.

PRUNING

Corrective pruning is necessary when frost, dieback, or insect damage destroys the terminal growth. Side branch pruning should begin early in the growth of the walnut seedlings to maintain a single stem. Attention should first be directed at any forks that are 2 or more years old. As the seedlings begin to reach a height of 3 to 4 ft, removal of a branch or two may be necessary. Experience has shown that the snipping of a branch or two rather than complete removal stimulates height growth. A seedling or sapling should have at least half the total height in live crown. Many growers have removed too many limbs stimulating height growth and causing small trees to fall over.

If weed and grass control is not wide enough and the seedlings are not tall enough, equipment striking the branches can break or tear them from the stem. This can be a very serious problem. A pruning technique we have used for many years helps to reduce the damage. Prune branches in the mid crown region to leave 8 to 10 in. stubs. This shearing has several advantages: (1) There are no long branches to damage in early spring when important cultural practices, such as spraying, cultivation, and mowing, are performed. (2) There is only a slight increase in the diameter of the stub left on the stem (a normal branch will about double in diameter). (3) Shearing forces height growth in early spring, but later lateral buds form new branches on the stubs bringing the tree into balance. (4) If equipment strikes the limb, only the new growth (which originates on the stub) will be torn off, leaving the main stem without injury. To produce high quality veneer logs, these sheared branches should be removed when in the lower 30 to 40% of the main stem.

WEED CONTROL

Particularly important in the first few years of a walnut plantation is controlling species of plants growing on the site that are deemed weed species. A useful way to approach this situation is for the grower to first define "weed." Tall fescue is a crop in an agricultural situation, but a definite weed in a walnut plantation. Brushy

shrub species or other tree species could be just the opposite. From an economic viewpoint, weed control is an expense and is incurred at the beginning of the walnut investment. The minimum amount that is required is all that should be done.

The objective of weed control is to establish walnut as the dominant species and keep the walnut trees in a "free-to-grow" condition. Certain other plant species are considered as weeds if they tend to outgrow and stress the walnut trees, or if they compete underground by robbing soil moisture and nutrients, or if they are allelopathic to walnut. Weeds need to be controlled during establishment and early culture of walnut plantations. An application of standard recommendations for establishment and early care of walnut plantations can result in a lessening of the need and expense of weed control.

Past work by foresters, landowners, and researchers has produced a wide array of techniques for controlling weeds, and prospective walnut growers may avail themselves of this technology easily. After the seedlings are planted, continued control of weeds around the growing trees can be by use of herbicides, by mechanical means, such as disking, or by both. Mowing may at one time have been considered as a technique for weed control; however, repeated mowing tends to favor grass and sod establishment, which is usually detrimental to walnut tree growth. This does not mean mowing has no place in plantation management. It is useful in keeping access for work around the trees in the future, for prevention of soil loss on highly erodible areas by maintenance of vegetation strips between the rows, and reducing risk of grass fires within black walnut plantations.

Herbicides have emerged as the most efficient and least expensive means of weed control. Postemergent herbicides can be mixed and sprayed on existing green growth and growing weeds to eliminate those weeds during the season of walnut tree growth. Pre-emergent herbicides are applied to the soil surface to prevent weed seeds from germinating, and a spring application can last through several weeks of the most active walnut growth. Herbicide application normally does not suppress all weed species for a bare ground appearance; however, it can control most weeds.

Conscientious site selection and preparation, judicious use of interplant species, and applied weed control for up to 3 years can result in fast initial plantation growth and a closing of crowns, giving shade on the ground. Activity could then quickly shift away from suppression of ground vegetation to management of upright woody stems to keep the walnut going as the dominant species. The array of equipment, spray systems, and chemical for weed control is broad and readily available.

Weed control discussion should acknowledge that appearance also may be an important factor. Interplanting and chemical weed control can give an unkempt appearance even though walnut growth is enhanced. Landowner objective is the most important component in land management decisions, and if a neat, mowed condition or appearance is a high priority for the grower, then that appearance should be sought. The balance between appearance and growth rate is a subjective decision, and some growers may wish to compromise the two at some median level. However, in walnut ventures wherein optimum growth and quality is the main objective, previous experience increasingly demonstrated that a woods-like condition may be the most desirable condition for a walnut plantation.

CONCLUSION

One great advantage in forest investments is the passive nature of those investments. Rigorously scheduled maintenance is not always required, and owners have flexibility to perform work activities as time allows. Most of the time, the trees are quietly growing.

With walnut plantations, the establishment and early care phase represents the time of greatest activity. A grower should examine the young planting to check for insects, wind, and disease damage. Activity eventually turns to side-bole pruning and thinning to promote quality and continued good growth of the crop trees. Most growers enjoy pruning and thinning for it is here that they begin to see the emergence of straight, clean stems on the way to becoming a quality timber crop.

HISTORY, ECOLOGY, SILVICULTURE, AND USES OF BLACK WALNUT IN FRANCE

Géry van der Kelen and Jacques Becquey[1]

ABSTRACT.—A historical portrait of black walnut (*Juglans nigra* L.) in France is present following its introduction in the 17th century as an ornamental tree. Other topics include its cultivation in coppice-with-standards stands at the end of the 19th century, the selection of exceptional trees, and its recent establishment in plantations with nurse crops. We describe the soil and climatic factors needed to grow black walnut in France along with silvicultural techniques currently being practiced. We also discuss why interest in black walnut seems to be declining when its cold hardiness and growth on favorable sites under forest conditions is superior to the Persian walnut (*Juglans regia* L.) or equivalent to the hybrid walnut *J. nigra* x *J. regia* (= *J. intermedia*). Finally, we describe the main uses of black walnut and give an overview of the future of this exotic species in France.

INTRODUCTION

American black walnut (*Juglans nigra* L.) was introduced into France in 1629 as an ornamental or shade tree for parks and botanical gardens (Rameau *et al.* 1989). Since the end of the 17th century or the beginning of the 18th century, interest in growing black walnut in plantations has varied because most forest managers are ignorant of the real potential of this precious hardwood species (Garavel 1960). The 'Gentilhomme Cultivateur' (Volume 2: 210) published in 1761 states "There is a kind of walnut someone calls Virginian black walnut; ... It grows naturally slowly; its fruit does not cost anything; ..." (de Jandin 1975). In 1867, the 'Société, centrale d'agriculture' launched for several years a contest with a prize as the planting of 500 black walnut seedlings (Guinier 1903-1904). Although results of these contests are unknown, one wonders why the propagation of black walnut is not more advanced and why this species has not been more frequently introduced into forests or to create new forest stands.

American black walnut was introduced in France in the 1830's at several locations. From 1837 to 1848, Professor Schützenberger, mayor of the city of Strasbourg, became such a fanatic of exotic species that he became qualified as 'Baumele Mayor' ('the mayor of bushes'). His accomplishments included establishing many black walnut plantations in parks and promenades of the city (Schwab 1990). The beauty of walnut as isolated trees, roadside plantings, or small groups in parks in various parts of France lead to interest in cultivating black walnut as a forest tree species for timber production (Guinier 1903-1904, Hickel 1935, Schaeffer 1909). In 1882, Rebmann, the imperial Prussian forest master of Strasbourg, began tests to introduce black walnut in Alsatian forests. Schaeffer (1909) discusses similar interests in silvicultural experiments with black walnut in forest stands in the basin of the River Saône where the soil from outwash fans would be equivalent of the Rhine diluvium.

Later, Gaussen (1946), Guinier (1953) and Toussaint *et al.* (1973) recommended the introduction of black walnut on alluvial soils in the

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Alsatian coppice dominated by pedunculate oak (*Quercus pedunculata*) and common ash (*Fraxinus excelsior*). These sites are managed as coppice-with-standards stands which consist of two distinct canopy layers. A low even-aged understory treated as coppice and an overstory of uneven-aged forest trees. The understory is cut as coppice allowing a certain number of saplings (i.e., oaks, walnuts) to grow into the overstory. Preference is given to trees originating from seedlings rather than sprouts. Because these trees will remain into the next rotation, the reserve trees must be carefully chosen.

Thus, in 1973, it was possible to count about 50 black walnut plantings totaling 60 ha in Alsace. These stands laid to the north in the Hagueneau forest and to the south in the Hardt forest with the strongest density situating in the plain around Colmar (i.e., Niederwald forest) and Strasbourg (Toussaint *et al.* 1973). This plain is probably the region of France that possesses the most numerous and the oldest stands where black walnut was introduced (Schwab 1990). The acquired experience and excellent growth of black walnut in Alsatian forests as well as its economic interest have encouraged others to pursue the introduction experiments undertaken by Rebmann. Silviculturalists have introduced black walnut in Normandy to enrich stands of oak-hornbeam (*Carpino-Quercetum*), oak-beech (*Fago-Quercetum*), or alder (*Alnetum*) (Aubert 1975). Currently, the planting of black walnut, along with other exotic tree species, is strongly questioned by ecologists (Ringele, pers. comm.). Likewise, new black walnut plantations were prohibited in Alsace from 1988 to 1990. It is also anticipated that the introduction of black walnut in the beech or poplar stands growing in the 'fen-car' (ultimate development state of a fen) will be eliminated to favor the return to forests composed of indigenous species (Schwab 1990).

Black walnut has remained a relatively rare species throughout France. Outside Alsace, it was planted for several decades to the south in the valley of the River Loire, in the valley of the River Saône, in the Franche-Comté, and in Normandy (Solignat and Jalinat 1970, Aubert 1975, Groupe detravail "Noyers à bois" 1994). Since the beginning of the seventies, a multitude of small plantations have been established in almost all regions of France (Groupe detravail "Noyers à bois" 1975-1996). Indeed, it was only at the end of sixties under a strong demand by manufacturers, especially cabinetry manufacturers, that private foresters began to establish walnut plantations for the exclusive production of walnut timber. In the past, the production of walnut timber was from the native Persian walnut (*Juglans regia*) managed for both nuts and timber, with the nut crop being the main objective. As the amount of walnut decreases, Persian walnut is again the main source of the walnut timber supply in France. It will be necessary that France begin to plant walnut for timber to renew this resource because often these trees are not replaced. The new intensive management of Persian walnut on boles as short as 1 m (3.3 ft) will not replace harvested trees (Hubert 1979, Becquey 1995).

Plantations introduced by silviculturalists at the beginning of the seventies have often given disappointing results because of the poor sites chosen by planters and improper techniques for establishment and cultivation of walnut. In 1975, the Institute for Forest Development (IDF - Institut pour le dèveloppement forestier) created a 'Walnut for timber' workgroup (Groupe detravail "Noyers à bois") to solve the problems confronted by planters (Hubert 1987). This group continues to meet twice per year. Although there is some interest in American black walnut and Persian walnut, primary emphasis is on the hybrid walnut (*Juglans intermedia*). Hybrid walnut is produced by crossing American black walnut and Persian walnut and has the greatest potential for the production of timber (Groupe detravail "Noyers à bois" 1975-1996).

Black walnut has not been widely recommended in France because it flushes early in the spring exposing the new growth and flowers to late spring frosts and because the wood is too dark and has violaceous reflections (Garavel 1972). These two important hindrances have appreciably slowed research on black walnut in favor of the other walnut species and have discouraged consultant foresters and private forest owners from planting it. This explains why during the last 25 years, fewer black walnut plantations have been established in France than those of the Persian and hybrid walnuts. As subsidized by the National Forest Fund (FNF) from 1989 to 1992, the total plantation acreage of walnuts established for timber has annually ranged from between 600 and 800 ha (243 and 324 acres) (DERF-AFOCEL in Becquey 1995). This compares to 200 to 300 ha (81 to 122 acres) annually

from 1969 to 1987. Unfortunately, since 1985 less than 5% of this acreage have been planted in black walnuts!

Under the impetus of the 'Walnut for timber' workgroup, black walnut has been established in many small comparative plantations to determine the site and cultural conditions needed to produce quality black walnut in France. Efforts have been made to locate exceptional black walnuts growing as isolated trees, in roadside plantings, or small stands to collect seed of these trees for progeny testing. Unfortunately, the successful establishment of black walnut still remains a problem. Fortunately, with the passing of time, it appears that many old plantations will yield very satisfactory results in the future. With more experience, forest managers may again desire it and begin planting it again, at least on sites that are suitable for American black walnut.

ECOLOGY AND SITE REQUIREMENTS

Because of its greater height, circumference, and volume at maturity, American black walnut needs more growing space than Persian walnut (IDF 1983). Black walnut regenerates well in forest stands because it competes better with other tree species than Persian walnut (Rebmann 1903, de Jandin 1975). In addition, black walnut is less sensitive to shade, produces a higher quality bole, and has more forest-like growth habit than the Persian walnut. Thus, when black walnut grows in clumps or small stands, competition from neighboring trees produces a straight central stem typical of trees in dense forests (Schaeffer 1909). Less plastic than the Persian walnut, black walnut is not recommended for planting at altitudes higher than 600 to 700 m (IDF 1983, Bazin 1992, Crave 1994). On good sites, black walnut can grow very rapidly to reach a height of 30 m and a diameter varying from 65 to 130 cm in 70 years. Volume increases of 1 m^3/ha/year from timber have been reported and several trees have been harvested with more than 18 m^3 of timber (Garavel 1959, Martin 1972). On good sites, black walnut also reaches its cutting age (around 50 to 65 years) more rapidly that Persian walnut (Bazin 1992). Its diameter increment may exceed 10 mm/year on some sites (Bazin 1992).

EDAPHIC FACTORS

Black walnut has be classified as being a mesohygrophillous or possibly a neutrophilous species in France (Rameau *et al.* 1989; Walliser, pers. comm.). It grows very well on sites where common ash, poplar (*Populus* sp.), and pedunculate oak grow vigorously. For rapid growth, black walnut has to be planted in soils rich in organic matter and minerals (IDF 1983, 1997). In Alsace, these soils are characterized by an understory of herbaceous plants including *Primula clatior, Hedera helix, Milium effusum, Carex sylvatica, Stachys sylvatica, Circea lutetiana,* and *Adoxa moscatellina.* Plants like *Urtica dioica* indicate the presences of a humus layer rich in organic matter. Plants like *Allium ursinum* and *Arum maculatum* indicate well-drained soils (Toussaint *et al.* 1973; IDF 1983, 1996). Most of the best walnut currently growing in France is found on such soils (IDF 1983, 1997). The presence of *Deschampsia cespitosa* is an indicator of an unfavorable site, while sites covered with *Molinia caerulea* are to be reject as walnut sites (Toussaint *et al.* 1973).

Soil characteristics and water supply — The growth of black walnut is strongly conditioned by the physical properties of the soil. It must aggressively compete with common ash and poplar on many sites. Walnut should be established on soils with a depth of at least 0.90 to 1.50 m (3 to 5 ft) having a good structure with balanced texture and good water reserves (IDF 1983, 1997). It has, however, been successfully established on rich soils with a depth of only 60 to 80 cm (2 to 2.6 ft) that are well aerated and overlay a permeable subsoil (gley) (IDF 1983, 1997). Toussaint *et al.* (1973) also suggests planting black walnut on soil less than 40 to 50 cm (1.3 to 1.6 ft) deep if they overlay a permanent water table. In the Perigord, edaphic conditions judged ideal for black walnut species are the rich, homogeneous clay-siliceous alluviums (such as in the valley of the River Dordogne) above a thick gravel layer to insure adequate drainage and a deep groundwater table making soil moisture constantly accessible to the roots (Cabanel 1969). Black walnut grows poorly on dry soils.

Clay, compacted, or poorly drained soils (pseudogley soils) are to be avoided. These soils

become saturated with water during the winter and become too dry during summer. Likewise, acidic peat soils and silt-laden soils with poor structure should be avoided (IDF 1997). Black walnut can not develop its taproot on these soils resulting in poor growth early in the rotation. Gravelly and sandy soils should also not be planted because they are infertile, water filters through them to rapidly, and upward movement of water is restricted during dry periods (Becquey 1990a, IDF 1997). Although black walnut withstands temporary submersion better than Persian walnut, prolonged floods reduce growth by both walnuts due to root destruction (IDF 1983, 1996; Mapelli 1995). The 'Walnuts for timber' workgroup suggests planting walnut only on soils that have good internal drainage with adequate soil moisture all year round (IDF 1997).

Acidity — Black walnut develops better that the Persian walnut on acidic ground or soils with a pH of 5 or less (IDF 1983, 1997). By grafting Persian walnut to black walnut rootstocks, Persian walnuts for nut crops have been planted on acidic sites with a well balanced physical structure such as the decalcified clays and schistose soils in Corrèze and to the north of Dordogne (Cabanel 1969).

Black walnut becomes chlorotic in very carbonated soils with a pH of eight or more. Cloggings as found in some forests in the valley of the River Saône lead to asphyxiation of the root system. Conversely, strong to moderately carbonated soils may also lead to chlorosis (Becquey 1990b). However, it seems that some walnut trees are less sensitive than others to high pH. Becquey (1990a) suggests using seed from walnut trees growing on sites whose pH is equivalent to that of the planting sites.

CLIMATIC FACTORS

Temperature — High summer temperatures are not harmful to black walnut if adequate soil moisture is available either from precipitation or the water table. For example in Alsace, summer precipitation and the water holding capacity of the alluvial soils compensate for the high summer temperatures (Toussaint *et al.* 1973). Black walnut tolerates cold winter temperatures better than the hybrid or Persian walnut, especially in areas where rapid cooling occurs after periods of more clement temperatures (IDF 1997). There has been some selection for improved cold resistance in black walnut (Martin 1972, Becquey 1990b). In the Alsatian plain, it is not uncommon to record winter temperatures as low as -25°C. Toussaint *et al.* (1973) mention that the risk of frost splitting is great, especially on black walnut growing on water saturated, poorly aerated soils. The cold temperatures that occurred during January 1985 produced many frost cracks on black walnut trees.

Spring frosts — The sensitivity of black walnut to spring frost is one defect leading to a preference for Persian or hybrid walnuts (IDF 1983, 1997). Black walnut in France is particularly sensitive to spring frosts because it generally flushes 10 to 15 days sooner than Persian walnut (de Jandin 1975). Spring frosts destroy the young shoots and favor the formation of forks or crotches (de Jandin 1975). The resulting poor stem form underlines the importance of selection of later flushing phenotypes (Martin 1975). The problems associated with spring frosts can be lessened if walnuts are grown on good soils or if regularly pruned to maintain a clear bole free of forks (IDF 1996). Black walnuts with good form have been found in regions noted for last spring frosts such as Normandy, the Franche-Comté, and the Auvergne (Cabanel 1969); however, one should avoid planting black walnut in frost holes (Becquey 1990b).

Frost damages occurs more frequently in unprotected or open plantations than in plantations grown under shelter, in strips, or 'slides' (Rebmann 1903, Schaeffer 1910). The technique of 'slides' as developed by Rebmann in the beginning of the century is described as opening 0.8 m (2.5 ft) wide silvicultural lines through 3- to 6-years-old coppice or pine sapling stands. These cleared lines are cultivated before planting germinated nuts every 1.2 to 1.4 m (4 to 4.6 ft) along the lines. Because black walnut is heliophilous, it is necessary after 2 or 3 years to decrease the overstory intensity or to widen the lines. After 8 to 10 years when the walnuts are close to 7 m (23 ft) tall, the entire overstory is removed (Schaeffer 1909).

Wind — Black walnut should not be planted on sites exposed to frequent and/or violent winds. It is very susceptible to crown or branch breakage, especially before the first thinning (IDF 1983, 1997; Becquey 1990b). After the first

thinning, one should try to create, reconstitute, or maintain a forest-like atmosphere to protect young saplings. This can be achieved using high densities, mixing with other forest trees, or planting with woody nurse crops (IDF 1983, 1996; Becquey 1990a). On sites with frequent and/or violent winds, lateral shelter from either windbreak hedges or planting on slopes opposite the prevailing wind is indispensable (de Jandin 1975). Other options include choosing Persian walnut or the less sensitive hybrids on exposed sites.

Pest Problems — Black walnut is less sensitive than Persian walnut to root diseases. It is more resistant to *Armilaria melea* fungi and is sometimes parasitized by *Viscum album* (Martin 1975). Black walnut like Persian walnut requires protection against rub damage by deer (*Cervus elaphus* and *Capreolus capreolus*), browsing from the old world rabbit (*Oryctolagus cuniculus*) and the European hare (*Lepus europaeus*), and stem girdling by voles (*Microtus* sp.). Where *Capreolus capreolus* is particularly abundant, it is impossible to find undamaged seedlings in plantations without deer protection. Browsing damage is usually less severe than deer rub damage. In the Sélestat forest, black walnut seedlings seem to be little attacked by the *Dama dama* (Toussaint *et al.* 1973). In agricultural regions, black walnut is attacked by the same insects as Persian walnut with the common insect pests being *Zeuzera pyrina* and *Ceresa bubalus*. Nuts sown in open fields must be protected from predation by voles and corvids (*Corvus* sp.) (IDF 1983, 1997).

BLACK WALNUT SILVICULTURE

FOREST AND FARMLAND ESTABLISHMENT

Black walnut is most often established in forest clearings, in the middle of low coppice stands, or after harvesting of simple coppice or coppice-with-standards stands (Guinier 1903-1904, Schwab 1990). Walnuts are usually planted at wide intervals to allow planting of pedunculate oak or natural establishment of common beech (*Fagus sylvatica*) which help to avoid soil degradation and insure natural side branch pruning (Schaeffer 1909). In some forests, silvicultural lines are established across the site by alternately cutting 5 m (16.5 ft) wide bands. Because black walnut is very sensitive to competition for light, plantings including those under forest shelter need regular and high-cost thinnings to provide full sun light to the developing walnut seedlings and saplings (Garavel 1959).

After harvesting coppice, it is often desirable to use natural regeneration and regrowth to provide side shade to train the black walnut seedlings and saplings. Although lateral shelter is beneficial on shaping the walnut bole form, it is imperative that the competition does not overtop the walnut (IDF 1983, 1997; Becquey 1990a). Rebmann (1903) found that 5 years after planting, walnut without a woody nurse crops were 30% shorter than walnut with woody nurse crops. According to Rebmann (1903), black walnut has growth near that of pedunculate oak, thus black walnut could be cultivated in forest stands using the regular high forest system if plantings were thinned early and regularly.

On former farmland, black walnut is often planted in pure stands with wide spacing (6 to 12 m (20 to 40 ft) in both directions) much like Persian walnut in nut orchards (Groupe de travial Noyers à bois 1975-1996). In some cases, cereal crops are grown between the walnut trees during the first 5 to 10 years after planting (Becquey 1991, Groupe de travial Noyers à bois 1975-1996). Other options include planting a nurse crop for soil protection such as basswood (*Tilia cordata*), the common beech, the hornbeam (*Carpinus betulus*), or alder (*Alnus cordata or A. glutinosa*) (Rebmann 1903, Becquey 1991, Bazin 1992). Interplanting of shrubs such as black elder (*Sambucus nigra*), autumn olive (*Eleagnus umbellata*), or hazel (*Corylus avellana*) has also been recommended to provide the side shade needed to encourage development of straight boles on black walnut (Courraud 1990, Bazin 1992).

In valley sites with high quality soils, interplanting black walnut with poplar, especially clones with narrow crowns can be successful (IDF 1983). If the poplars will be harvested for timber, the two species should probably be planted in alternate rows to limit harvesting damage during poplar felling. To provide adequate sunlight when using an equal mix of both species, densities should not exceed 50 walnuts and 50 poplars/ha (246 trees per acre) (Becquey 1990a, IDF 1997). More research is needed before this silvicultural practice can be recommended.

PLANTATION ESTABLISHMENT

Garavel (1959) does not recommend direct seeding in open fields; however, sowing nuts to establish black walnut is conceivable on forest sites under a light shelter of coppice to reduce the risk of frost damage or in small gaps. Direct seeding has been successfully employed in some coppice-with-standards stands of the valley of the River Saône. Although young seedlings benefit from overstory shelter the first year (Garavel 1959), the overstory has to be suppressed rapidly for seedlings to survive in subsequent years (IDF 1983, 1997).

For direct sowing, 120 to 200 holes/ha are prepared by loosening soil with a spade or pickax to a depth of 40 to 50 cm (1.3 to 1.6 ft) before sowing three nuts in each hole. This will help insure rapid seedling growth. The site has to be cleared of all vegetation within 1 m (3.3 ft) or more of each hole along with providing protection from rodent and bird pilferage (IDF 1983, 1997). In some plantings, manure is added when preparing the holes (Aubert 1975). If more than one seedling germinates, the less vigorous seedlings are suppressed later by cutting them below the root crown to prevent them from sprouting (Garavel 1959, IDF 1997). Aubert (1975) also recommends the coppicing of seedlings without good stem form after 2 to 3 years and suppression of lateral buds to avoid precocious lateral branching.

Most black walnut plantations are established with nursery produced seedlings. Generally, 1 year old seedlings (1+0) taller than 30 cm height or 2-year-old seedling (1+1) at least 80 cm tall are transplanted (IDF 1997). Becquey (1993) suggests avoiding use of 2-year-old non-transplanted seedlings (2+0) or seedlings older than 2 years because they are difficult to transplant. In addition, their heights often exceed 2 m and are easily damaged by wind. Containerized seedlings are also not recommended because these seedlings are often filiform and have underdeveloped root systems.

PLANTATION SPACING

Spacing recommendations in the past have been quite variable ranging from 4 to 5 m square to avoid damaging trees during future thinnings, the preferred 5 to 6 m square, to 10 m (32.8 ft) square to promote rapid diameter growth (Rebmann 1903, Aubert 1975). In some Alsatian forests, managers are using far closer spaces of 1.5 to 3 m square or 2.2 m x 1.2 m (Anon. 1979). The recommendations for minimal plantation densities for black walnut are between 150 to 600 seedlings/ha. Densities of 400 to 600 seedlings/ha allow for selection during future thinnings and reduces the amount of crown and side branch pruning needed (Becquey 1991).

Currently, the 'Walnuts for Timber' Workgroup recommends several spacings with the choice been made based on the existing vegetation, types of seedlings available, and management objectives. These include close spacings of 4 to 5 m square or 3 m within lines with lines spaced 4 to 6 m apart, as well as, wide spacings of 7 to 12 m square or 4 to 8 m apart within lines with lines spaced 12 m apart (IDF 1983, 1997). Due to the expected natural regrowth, spacing in forest clearings is more important than on a former farmland without woody vegetation. In forest clearings, large 2- to 3-year-old seedlings are planted at wider spacings then when using 1-year-old seedlings. Under intensive management with frequent passages of equipment through the planting, most managers usually prefer the wider spacings.

Wide spacings will reduce planting costs, but demands more intensive management, especially for crown and side-branch pruning, in subsequent years. In wide spaced plantations, it is possible to interplant other tree species as nurse crops such as alders (*Alnus* sp.), black locust (*Robinia pseudoaccacia*), hazel, or other high-value hardwoods such as cherry (*Prunus avium*) or common ash. Nurse crops diversify the planting if site conditions are not favorable for walnut and can produce additional wood products when plantings are thinned (IDF 1983, 1997; Becquey 1990a, 1991).

PLANTATION MAINTENANCE

Controlling competition — Under wide spacings, trees within rows are maintained by manually hoeing during the first years, or sometimes, by using herbicides. Installation of a mulch has also been recommended to reduce maintenance around newly planted walnuts (IDF 1983, 1997; Becquey 1991). On former farmland, mechanical control of competing vegetation is often done with shallow discing or rototilling.

Crown and side prunings — Due to its sensitivity to late frosts, black walnut seedlings and saplings often develop forks which must be eliminated by crown thinnings. Under wide spacings, annual crown pruning operations are indispensable. Crown pruning is also used to correct defects caused by the wind or insect damage from *Zeuzera pyrina* (IDF 1983, 1997). When the vigor is good, black walnut sometimes resemble a 'whining willow' (*Salix alba* x. *S. babylonica*). The walnut trees produce more than 1 m of new growth on each branch that bends under the weight from the large number of leaves and wind (de Jandin 1975). Branches whose diameter exceeds 3 cm (1.2 inches) should be removed as soon as possible to minimize defects in the wood. Lateral branch pruning should be done gradually removing branches only from the lower one-third of the tree. The minimum tree height before beginning side-branch pruning is 2.5 m (Bazin 1992). Because black walnut has a more forest-like habit and generally develops a longer stem, the maximum pruning height is generally 6 to 8 m, higher than for the Persian walnut. Walnut trees pruned higher than this tend to break under high winds and can seriously damage the log (IDF 1983, 1996). When black walnut is grown under wide spacings, the traditional techniques used for Persian walnut in nut orchards are also used with black walnut to produce 2 to 3 m high clear butt logs (Becquey 1993).

Thinnings — In traditional close-spaced plantations as in the Alsace region, foresters release young walnuts 6 to 8 years after planting or when the trees reach a height of 4 to 5 m. In forest stands, where walnuts are grown with other woody species, thinnings usually begin 16 to 17 years after planting and then every 6 or 8 years until all trees are harvested. Thinnings remove trees from both the understory and overstory. The major objective of thinning is to allow the black walnut trees to reach the overstory (Rebmann 1903).

If the management objective is to harvest within 40 to 60 years approximately 60 walnut trees/ha with stem diameters exceeding 55 cm (21.6 in.), then the first thinnings must occur early even with relatively wide spacings. Becquey (1993) suggests to begin thinning as soon as the canopy closes to favor diameter over height growth. According to him, on former farmland on spacing of 6 m or 7 m square, thinning operations may begin at an age of 16 to 22 years on good or medium quality sites. Walnut trees should then have reached a height of 15 to 20 m and a stem diameter between 20 and 30 cm. In this type of intensive silviculture (ligniculture), the poorer formed walnuts are removed during the first thinning retaining the trees with the best timber quantities (Becquey 1993). After the first thinning, there should be 120 to 140 trees/ha of high quality walnut remaining (Bazin 1992).

SECONDARY UTILIZATION

ROOTSTOCKS FOR PERSIAN WALNUT

Recommendations for use of black walnut as a rootstock for Persian walnut were not effectively developed until after the first world war; however, it was recommended as early as 1811 and used in Isère from 1850 to 1960. Black walnut rootstocks were used to reduce attacks by *Armilaria melea*, a root pathogen that infects nut orchards grafted on Persian walnut rootstock (Solignat and Jalinat 1970). Grafting to black walnut has only one purpose, that is, nut production. All the grafting techniques known, including root grafting, were usable (Treyve 1936). The most commonly used scion during the sixties was the variety *J. regia* 'Franquette' (Cabanel 1969).

Nut trees grafted on black walnut trees frequently showed increased vigor, better resistance to root diseases, more rapid fruiting, and generally a 5 to 10% increase in nut production compared to walnuts grafted on *J. regia* (Garavel 1959, Cabanel 1969, Charlot and Germain 1990). Some authors have reported increased vigor of Persian walnut grafted on black walnut, while others have reported increased nut production. Although young grafted seedlings are more vigorous, their development is weaker which can be compensated for by increasing tree densities (Germain *et al.* 1981). Indeed, utilization of *J. nigra* as rootstock has allowed for an increase of tree densities to 7 or 8 m square instead of the traditional 10 or 12 m square for walnut on *J. regia* rootstock (Cabanel 1969).

Nut orchards grafted to black walnut rootstocks, unfortunately, only have a 25 to 30 year productive life span because of a graft incompatibility induced by a virus (Garavel 1959). *J. regia* rootstocks tolerate the cherry leaf roll virus

(CLRV), while *J. nigra* rootstocks develop a hypersensitive reaction at the graft union. This produces a necrotic reaction at the graft union called 'black line', which effectively girdles the tree and causes rejection of the scion (Charlot and Germain 1990). Delbos *et al.* (1984) report that of the approximately one million walnut trees managed for nut production in France, less of 20% of the cultivars were grafted on *J. nigra* rootstocks. The first generation *J. nigra* x *J. regia* hybrids (F1) that seemed promising as a rootstock because of their vigor have inherited the hypersensitive character of the black walnut. Since the identification of the agent responsible for 'black line', the production of grafted seedlings on *J. nigra* rootstocks has appreciably decreased. Research is currently underway by back-crossing to produce vigorous, tolerant hybrid rootstocks that do not develop the hypersensitive reaction (Charlot and Germain 1990).

NUT PRODUCTION

When their blossoms are synchronized, some black walnuts introduced in France have the capacity to hybridize naturally with Persian walnuts. Because most black walnut trees are isolated from other black walnuts, they are frequently pollinated by wind-blown pollen from Persian walnut. Some black walnut trees have yielded 80 to 90% hybrids in their progenies. Scionwood from these trees have been grafted and planted as pollinators in Persian walnut orchards because of the demand for hybrid seedlings by tree planters. These hybrids are generally more vigorous, have less demanding site requirements than the parent trees, produce better rootstocks for grafting, and are better adapted for the production of timber (IDF 1983, 1997; Becquey 1990a). The oldest hybrid walnut known in France is a *J. nigra* x *J. vilmoriana* hybrid growing in the park of the de Vilmorin family at Verrières-le-Buisson near Paris. It was planted in 1815 and grew vigorously until the 1980's. In 1993, it measured 32 m (105 ft) tall with a stem diameter of 130 cm (51 in.), but now is showing serious decay problems.

The high genetic heterozygosity of hybrid walnut produces better winter hardiness, greater adaptive plasticity, and more rapid growth and development than that of the parent trees. For seedling grown from the nuts from the same tree, the growth of the hybrid seedlings is approximately 30% faster than for the black walnut seedlings (Solignat and Grente 1965). Jay-Allemand *et al.* (1990) have developed a visual technique to quickly identify the interspecific hybrid seedlings by means of morphological characteristics. Two- to 15-year-old seedling and saplings of black walnut can be differentiated by its fissured bark compared to the smooth bark of the hybrid walnuts (IDF 1997).

The nut of black walnut was considered by Guinier (1903-1904) to be 'more than mediocre fruit.' Black walnut can produce abundant nut crops; however, the hardness and thickness of its shell, in comparison to the Persian walnut, have excluded the utilization of black walnut as nut crops in France. The hard shell of black walnut makes it difficult to extract the nutmeats which usually account for approximately 18 to 30% of the weight of the nut. Garavel (1959) recommends their utilization as 'food for poultry after crushing or as fuel.' Fortunately, the pronounced taste of black walnut nutmeats is appreciated in culinary preparations, pastry, and ice-creams in North America.

CONCLUSION

On deep, well drained soils, American black walnut is well acclimatized in France. Its growth rate is faster than that of Persian walnut and equivalent to that of the hybrid walnut *J. nigra* x *J. regia* (= *J. intermedia*). Although its dark colored wood is not appreciated in France, black walnut is considered a high-value tree because its wood can be used in many wood products. It has seldom been planted in pure stands and is usually found in parks or small clumps of trees much like in the eastern United States. Prussian, Alsatian, and then Norman foresters have established numerous introduction trails in coppice-with-standards stands (production of coppice under an overstory of high-value trees). Success of these black walnut plantings has been determined mostly by the physical properties of the soil and some climatical conditions. Before the identification of the cherry leaf roll virus, black walnut seedlings were used as rootstock in Persian walnut orchards. Inspite of the lack of interest by walnut planters, American black walnut is a better timber producing walnut than *J. regia*. Black walnut creates a more forest-like environment and is resistant to more

pathogens than Persian walnut. The hard, thick shell and problems associated with extraction of black walnut nutmeats has excluded the consumption of the nuts in France. Because of the production of high-quality timber on favorable sites, the renewed planting of black walnut should be reconsidered in France.

ACKNOWLEDGMENTS

The authors wish to express their gratitude to J. Ringele, Forest Engineer and delegate of the Regional Director for the High-Rhine region, as well as, T. Kopp, Forest Technician, both of the Colmar office from the National Forest Office (O.N.F.) for information they provided on growing black walnuts in Alsatian forests. They equally thank M. M. Walliser, Chief Forester of the Strasbourg office at the O.N.F., Mrs. J. Unsel-Claveaux for her precious assistance with the German literature, and, finally, Dr. J. W. Van Sambeek for the English revision of this paper.

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THE GERMAN FORESTRY PROGRAM AND WALNUT CULTURE

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ABSTRACT.—We summarize our observations made during a week long tour through Germany forests many of which contain both native and black walnut. Forests are traditionally managed for high-quality veneer logs on a 250 to 300 year rotation. Climatic conditions in Germany are similar and many sites in the Rhein River valley are similar to our black walnut sites. Restrictions on site preparation, intermediate cultural treatments, and harvesting methods are having the same effect on German hardwood forests as our own mixed, oak-hickory hardwood forests.

To learn about German forest management, protection practices, and walnut culture, the Walnut Council scheduled a visit to Germany in May 1996. Though both the native walnut (*Juglans regia* L.) and plantings of our own black walnut (*Juglans nigra* L.) are rather widely distributed in Germany, it was apparent that German forestry places less emphasis overall on nut tree culture among its fine hardwoods than we do here in the United States. There are several reasons why this has been the case, at least in the past.

Forest industry in Germany utilizes large amounts of walnut wood for veneer, furniture, and various specialty products. German forest industry has imported significant amounts of walnut and other fine hardwoods, mostly from the United States and from tropical forests in Africa, Southeast Asia, and Central and South America. These woods in the past could be imported at costs economically favorable to the German forest industry. Two changing factors now influence raw wood imports. The German forest industry has a reputation for efficiency, innovation, and marketing skills which made wood import feasible. Several forest products industries have timber buyers particularly veneer buyers who operate throughout the world, including the eastern United States. Evidence of this activity was observed at the Fritz Kohl Furnierwerk (Veneer Mill) in Karlstadt am Main where we saw a large inventory of black walnut logs awaiting processing.

The Kohl Furnierwer mill processes 80 cubic meters of wood per day with 50 cubic meters of this being veneer. We were impressed with the skill, productiveness, and efficiency of the workers. Joachim Kohl, plant manager and family industry officer, and Walter Helferich, Chief Import Log Buyer who maintains an office in Smithfield, Kentucky, explained that overall prices for fine hardwood imports are gradually increasing due to worldwide competition for high quality logs and decreasing supplies of such wood from traditional sources in the United States and tropical countries. Higher prices for raw wood and decreasing supplies for imports have put more importance on intensive walnut culture and production in Germany as well as in the eastern United States.

At the Reinhausen Forest near Göttingen, we observed the harvesting of mature trees in a predominately oak-beech forest which also included American black walnut and European walnut plantings. This forest is state owned and obviously has much more intensive management than most of our privately owned forests in the United States. Growth appeared to be adequate

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on sites we would consider to be fair to moderately good for black walnut in the eastern United States. One site was a small stand of what is thought to be naturally established European walnut. The trees were vigorous and up to 20 in. in stem diameter. Curiously, one tree exhibited characteristics of both black walnut and European walnut. Since some plantings of black walnut were also in the vicinity, this tree might possibly be a naturally occurring hybrid.

As we traveled south and east in Germany, both planted and naturally occurring walnut of both species had better vigor, growth, and form. In the Reinhardshagen Forest near Sababurg is a virgin, primeval forest, which most of us would call an "old growth" or "Urwald" forest. This forest had 200- to 400-, maybe some 800-year-old German white oaks, some 150- to 400-year-old European beech, and a smattering of other species 100- to 200-years-old. Since 1850 all tree removal and grazing has been forbidden. Before 1850, the area was extensively cut and heavily grazed allowing Norway spruce to become established in areas depleted of nutrients and organic matter.

At the Spessart Forest near Rohrbrunn, we got an excellent overview of German forestry and forest operations from Forest Supervisor Herr Buerger. The Spessart Forest was the setting of the Grimm Fairy Tales. It contains extensive areas of both natural stands and old plantations including those of both black walnut and European walnut. The forests are dominated by European beech and German white oak on a 250 to 300 year rotation. At the site of a recent harvest, we saw a large number of large, nearly flawless veneer logs. Two items are worthy of special mention. First, the overall emphasis is on maximum quality, not on short rotations. Secondly, nothing produced in the Spessart Forest goes to waste. Veneer and high grade lumber logs go to the most appropriate mills. Lower grade logs are shipped to pallet, tie, and blocking wood mills. Remaining logs of still lower quality and smaller dimension go to pulpmills and firewood utilization. The smaller topwood and debris are scattered in the woods to add to the accumulating organic matter.

In the Rhein River valley near Freiburg, we saw several private- and state-owned forests several of which include black walnut. Of special interest was an old growth stand of walnut near the State Forest of Breisach. Many of these forests were on sites with bottomlands, coves, and gently rolling terrain similar to sites on which we grow our finest black walnut and other hardwoods. In this area we saw examples of nut tree stands, trials of natural regeneration, pruning and thinning cultural treatments, and management of mixed hardwood stands.

Historically, Europeans generally have preferred lighter colored woods; thus, the emphasis in Germany in the past on growing German white oak (*Quercus robur* and *Q. patraea*) and European beech (*Fagus sylvatrica*). Lately, the darker colored woods are starting to gain in popularity within German markets. The native walnut occurs mostly as scattered individual trees in German forests. However, German foresters are finding that intensive culture of both black walnut and the native walnut appears to be both biologically and economically feasible. Therefore, German foresters are giving nut tree culture more attention. As one German forester commented, "If we can grow some of the world's finest white oak, why shouldn't we be able to produce fine quality walnut?"

German foresters have been successfully managing their forests for over 400 years. Their comprehensive and intensive approach to multiple-use management of forestlands was evident in the Bismark Forest near Hamburg. The professional foresters who manage this private forest repeatedly stressed the importance of continuity for good forest management and stewardship in order to attain optimum diversity and multiple-use productivity. The Bismark forest was definitely a good example of proper forest management. They also emphasized the necessity of maintaining good records and "hands-on" management. They were particularly interested in the experience of American walnut growers with intensive nut tree culture and management. In spite of their long tradition and renown as excellent forest managers, many German foresters believe Americans have a sizable head-start in nut tree culture and were eager to learn from us. German foresters have always placed emphasis on high quality. Their 250 to 300 year rotations of German White Oak testify to this. We talk about 50 to 100 year rotations for "economic maturity" of our hardwoods in the Central States.

German foresters definitely pursue the "crop tree" system, as we also profess to do in the

United States. However, their overall management is much more intensive than ours, particularly in native stands. Their walnut practices raised new questions for us. For example, how is it that they successfully summer-prune nut trees whereas we advocate dormant season pruning? How do they achieve natural nut tree regeneration so successfully? Several German foresters told us they believe they can continue to produce high quality trees with shorter rotations than they are currently using. In native stands, they believe as we do that there is a "happy middle-ground" - a compromise - between maintaining quality while achieving shorter rotations. Their experience with long term intensive management should lend itself quite well in managed plantations, especially for increasing nut culture as part of walnut management programs.

The German foresters share a common concern about the future use of their hardwood forests as do our American foresters. Foresters everywhere are being told by people without training in the natural resources what they can and cannot do in or with the forests. These groups, including special interest groups such as radical "environmentalists," politicians, and other lackeys, have their own agendas. Everyone deserves to be heard but the particular agenda of some of these groups appears to be in conflict with ecologically sound forest management and stewardship of our forests. Restrictions on site preparation practices, intermediate cultural treatments, and harvesting methods are having the same effect on German hardwood forests as they are in our Central Hardwood forests. Mixed hardwood stands of white oak in Germany and in our oak-hickory, mixed hardwood stands are both being replaced by beech-maple stands.

We walked many hectares of German forests where harvest restrictions are in effect and saw little or no oak regeneration. The dominance of the shade tolerant beech and maple does not bode well for less shade tolerant species such as black walnut, native walnut, oak, or their associate species. The best natural regeneration of shade-intolerant oak we saw during the entire tour of German forests was in a stand decimated by a severe windstorm 2 years ago. We do well to remember that nature manages by areas, not tree by tree, and that we do our best management when we emulate nature - not fight it!

Forest protection problems in Germany generally parallel ours. Decay diseases are present along with hardwood borers and defoliators such as the gypsy moth. Their climatic stresses, including drought, floods, ice and snow damage, and windstorms, are similar to those in the Central Hardwood region. German foresters appear to be doing a better job overall than we do in matching species to site conditions in order to minimize climatic stresses. The Rhein River valley and its major tributaries include many sites similar to our own black walnut sites. Wildfires are less of a problem in Germany then here. Forest grazing by domestic livestock is closely controlled and in many areas "Streng Verboten" - absolutely prohibited. Excessive deer browse is a problem both in Germany and in the eastern United States.

The German people have a strong affinity for their forests. From central to southern Germany, from mountains to river valleys, and from state forest to private forests, we observed many facets of German forestry as well as walnut culture. Many thanks are due to the German foresters who contributed their time and shared their knowledge with us. We were all more than ready to go back with more questions and hopefully more answers for the German foresters also. We already know that with walnut growers, one answer always generates a barrage of more questions.

INSECTS AND BLACK WALNUT: WHAT CAN WE EXPECT IN PLANTATION ENVIRONMENTS?

Marc J. Linit and W. Terrell Stamps[1]

ABSTRACT.—The establishment of black walnut plantations, especially in the Midwest, has increased in recent years. Plantation landscapes result in increased concentration and apparency of resources (leaves, shoots, nuts, etc.) utilized by insect herbivores and will influence host plant - insect interactions. The life history characteristics of an insect herbivore determines it ability to rapidly increase in abundance and thus its capacity to attain outbreak densities. Understanding the impact of resource concentration on insect herbivores, and the biological interactions between insect life histories and plantation management practices should facilitate pest management in a plantation landscape.

Black walnut, *Juglans nigra* L., is an indigenous tree species that grows over a large portion of the United States east of the 100th meridian. It is a component of many of the eastern forest types but is seldom abundant. It occurs as a minor species in a few forest types and is generally found scattered among other trees. Pure stands are rare and usually found on the edge of the forest (Fowells 1965). In its native habitat, black walnut has few important insect enemies. The establishment and management of black walnut plantations, especially in the Midwest, has increased in recent years. Will the plantation landscape change the dynamics of insect herbivore-black walnut interaction? If so, what does this mean to the resource manager?

PEST OUTBREAKS IN FOREST ENVIRONMENTS

Stands of trees occurring as natural forests or as forest plantations are host to numerous species of herbivorous insects. Most of these species remain at relatively low, stable population densities. These species are sometimes noticed but rarely are of economic importance. Other insect species are characterized by large, sometimes spectacular, fluctuations in their population densities. These species are highly evident when at high density and are often responsible for significant economic impact. The extent to which an individual species expresses these characteristics is determined, in large part, by its life history. Price (1994) suggested a close linkage exists among the phylogenetic background, adaptive traits that optimize opportunities and pattern of population dynamics exhibited by tree feeding insect herbivores. This interaction results in two types of forest herbivores, latent and eruptive species.

The abundance of latent species of forest herbivores is closely tied to the population dynamics of the resources which they utilize for oviposition and larval development. Adult females locate and oviposit into living and developing plant tissue which will become the larval food source. This maximizes larval survival because the egg is placed into the larval habitat. These oviposition sites are often large plant modules, such as fruits or nuts, which are usually uncommon or rare compared to modules such as twigs or leaves. This life history pattern results in the exploitation of uncommon resources; thus the herbivore will remain relatively uncommon in the environment and its population density will be as stable as the supply of resources.

The abundance of eruptive species of forest herbivores is not linked closely with larval host preference. Adult females of these species do not

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select the place where their larvae will feed. Eggs are commonly deposited on bark, rocks or other objects, often many months before larval feeding begins. The larvae commonly have a wide host range and can feed on many types of plant tissue, often foliage or twigs, in great abundance in the forest. Larvae of eruptive species with a narrow host range can develop on food of varying nutritional or physical quality. With an almost unlimited food source, populations of these species can attain extremely high densities and cause great economic damage to the forest. The gypsy moth is an excellent example of an eruptive species.

SIMPLIFICATION OF PLANT LANDSCAPES

The cultivation of black walnut in single-species plantations is a relatively new practice compared to the management and planting of many other economically important fruit and wood producing forest trees. Conventional wisdom suggests that insect problems should be worse in a plantation landscape compared to a natural forest. The ecological theory of associational resistance (Tahvanainen and Root 1972) states that plants grown in association with taxonomically diverse plant species suffer less herbivore attack than plants not so associated. Two hypotheses have been developed to explain the mechanism(s) of associational resistance: the enemies hypothesis and the resource concentration hypothesis (Watt 1992).

The enemies hypothesis (Root 1973) predicts that natural enemies (insect parasitoids and predators) will be more abundant in multiple species plant landscapes than in monocultures, therefore insect herbivore densities will be lower. Predators and parasitoids may be more abundant in complex plant systems than in monocultures for a variety of reasons. Complex systems provide refuges for hosts or prey thus stabilizing predator-prey and host-parasitoid associations by preventing natural enemies from driving prey or host populations to extinction (Root 1973, Watt 1992). Natural enemies in complex systems can utilize a greater variety and abundance of hosts or prey. They should have access to a greater variety of hosts or prey through time as different insect species become available during the season (Andow and Risch 1985, Sheenan 1986, Letourneau 1987). Mixed plantings can also provide more nectar and pollen for adult parasitoids than would be found in monocultures (Bugg *et al.* 1987, Andow 1991).

Russell (1989), reviewed tests of the enemies hypothesis in crop systems. He reported that nine published studies found higher mortality rates from predation or parasitism in more diverse versus less diverse systems, two studies found lower mortality rates and two studies found no difference. The larvae of *Pieris rapae* (L.) were preyed upon at higher rates by ground beetles and harvest spiders in complex plant systems than in monoculture (Dempster and Coaker 1974). Altieri and Schmidt (1986) reported that predator density decreased with a decrease in vegetational diversity in abandoned, organic and commercial apple orchards. Predation was highest in orchards with the greatest plant diversity and herbivore density decreased.

Little research has been done on the enemies hypothesis in forest systems, though the same principles should hold true for trees as for agricultural crops. In one study, ground-dwelling predaceous carabid beetles were found to be more abundant in mixed broadleaf/pine stands than in pure pine stands (Butterfield and Malvido 1992). Wood ants, significant predators of many insect species in temperate forests, were found in greater numbers in mixed species stands than in single species stands (Laine and Niemela 1989, Watt 1992). Increased ant abundance resulted from the presence of a diverse aphid species complex which provided a consistent source of honeydew for the ants in the mixed stands (Laine and Niemela 1989).

The resource concentration hypothesis (Root 1973) states that plants are less apparent or attractive to insects in a multispecies plant environment than in a single species environment. This theory is based on the behavior of herbivorous insects and how they receive visual and chemical stimuli from host plants. According to this theory, insect herbivores are more likely to locate and remain on plant species that are grown in large, dense, pure stands. Under these conditions, they are less likely to be effected by interference from non-host plant species (Altieri 1994). Thus, target plants are less "apparent" to pests in mixed plantings compared to those grown in monoculture. Additionally, herbivores are more likely to leave polycultures

because the probability of landing on non-host plants is high and continued searching may lead them out of the area (Andow 1991).

Evidence supporting the resource concentration hypothesis comes primarily from agricultural crop systems (Risch *et al.* 1983). The corn leafhopper, *Dalbulus maidis*, emigrated from mixed cultures of maize and beans at significantly higher rates than from monocultures of maize (Power 1987). Two cabbage aphids, *Brevicornye brassica* (L.) and *Erioischia brassicae* (Bouche) immigrated at significantly lower rates into mixed species crop systems compared to monocultures (Dempster and Coaker 1974). Risch (1981) reported that lower beetle population densities found in beans planted with other species compared to a monoculture was due to the effects of resource concentration in the pure stands of beans.

Plants may be visually or chemically less apparent to insect herbivores when grown in association with other plants. Crops that stand out against bare soil are more readily colonized by aphids than crops with weeds (Smith 1969), crops with interplanted cover crops (Dempster and Coaker 1974), or with crops having green burlap between rows to conceal the soil (Smith 1976). Green burlap sacks or peanut plants placed between rows of maize reduced the visual apparency of the crop and reduced the number of corn borers, *Ostrinia furnacalis* Guenee (Litsinger and Moody 1976).

Chemical stimuli are utilized by many insect herbivores to locate their host plants. Non-host plants in association with host plants may mask chemical cues for herbivores or might act as chemical deterrents to herbivores. Tomato leaves, for example, repel flea beetles on collards (Tahvanainen and Root 1972) and cotton (Perrin 1977) under laboratory conditions. Field plots of beans sprayed with weed extracts were found to have fewer leaf-hoppers than fields sprayed with water (Altieri *et al.* 1977).

No studies designed to examine the resource concentration hypothesis have been conducted in forest systems because of the difficulty of manipulating forest stands to experimentally test the hypothesis. The principles involved, however, should operate in forest systems as they do in crop systems.

PEST PROBLEMS IN FOREST PLANTATIONS

Many land managers assume that damage from herbivores will be worse on trees in forest plantations than in natural forests. Surprisingly, there is little research evidence to support this idea. The nun moth, *Lymantria monacha*, caused widespread devastation to European conifer plantations in the 1920's. However, similar damage to natural conifer stands occurred (Gibson and Jones 1977). Some bark feeding and wood boring insects, usually restricted to attacking logs and unhealthy trees, can become problems in single species plantations (Gibson and Jones 1977). Defoliators, such as the spruce budworm, have greater survival as stand crown closure increases and survive better in stands with a high percentage of their host trees (Kemp and Simmons 1979). Gibson and Jones (1977) suggest major pest problems are more likely to occur at the establishment and early stages of a forest plantation, with herbivore problems diminishing as crop trees get older.

It must be noted, however, that insect problems can be the result of plantation management practices and not merely the result of resource concentration. Such practices include the planting of exotic tree species which may be susceptible to herbivory, poor site selection or site preparation, weed control that may destroy refuge sites for natural enemies or pruning practices that provide sites for herbivore attack (Watt 1992).

Plantation management can also enhance pest management efforts. Growers can select herbivore resistant tree species. The economics of intensive plantation management may allow greater expenditures on control measures and the compact nature of plantations allows for more effective application of control measures through improved access to the trees.

INSECT PESTS OF BLACK WALNUT

Many species of insects are associated with black walnut, however, few are pests of importance. Insects of Eastern Forests (U.S. Department of Agriculture 1985) lists 65 species of insects affecting the genus *Juglans* and black walnut (Marshall 1989). Kearby (1975) collected 62 species of insects associated with black walnut plantations in Missouri, and Nixon and McPherson (1977) listed approximately 300 species from plantations in southern Illinois.

Marshall (1989) discussed the importance of insects affecting the growth and quality of black walnut trees. He presented information on numerous species of insects but suggested that relatively few should be of concern to black walnut growers: walnut shoot moth *(Acrobasis demotella* Grote), ambrosia beetle (*Xylosandrus germanus* (Blandford)) and periodical cicada (*Magicicada* spp.) because of their impact on wood quality; the walnut shoot moth, walnut caterpillar (*Datana integerrima* Grote & Robinson), fall webworm *(Hyphantria cunea* (Drury)), oystershell scale (*Lepidosaphes ulmi* (L.)) and ambrosia beetle because of their impact on tree growth. To this list we add the black walnut curculio, *Conotrachelus retentus* (Say), an insect which impacts nut production in black walnut plantations (Linit and Necibi 1995).

WHAT CAN WE EXPECT IN BLACK WALNUT PLANTATIONS?

The propagation of black walnut outside the forest, its evolutionary home, changes the dynamics of insect-plant interactions. Establishment of a black walnut plantation results in resource concentration and increased plant apparency. However, plantation management practices may affect the survivorship of insect herbivores and their natural enemies, especially those which overwinter in the soil. How insect herbivores react to this new landscape will depend upon the interaction of the insect life history and management decisions made by the land owner. Below, we examine four types of insect herbivores that feed on black walnut; a nut feeder, a defoliator, a shoot borer, and a sucking insect. We discuss aspects of their biology and plantation management decisions which may influence their success in a plantation environment.

The black walnut curculio develops in the nuts of black walnut and butternut. Currently, nuts are an uncommon plant module and are produced in abundance irregularly. The female deposits an egg within a developing nut. The larvae feeds within the nut causing it to drop prematurely (Blair and Kearby 1979). The pupal stage and the overwintering adult stage occur within the litter layer or soil. The curculio has many characteristics of a latent species. Its abundance is determined by the availability of nuts during the previous year (Linit and Necibi 1995). This relationship can be expected to hold as new walnut varieties are developed to increase the nut bearing capacity of the tree. Growers are not likely to experience outbreaks of the curculio but as nuts become more abundant in black walnut plantations the abundance of the curculio is likely to increase. Management of ground vegetation within the plantation may be disruptive to the curculio life cycle and may prove to be a valuable pest management tactic (Linit and Necibi 1995).

The walnut caterpillar is the most destructive leaf feeding insect that occurs on black walnut. The female deposits a mass of eggs on the underside of leaves, often along forest margins or in forest openings, or on open grown trees such as ornamentals or trees in plantings (Farris and Appleby 1979). The larvae feed on leaves of several species in the Juglandaceae including walnut, butternut, pecan, and various species of hickory. If leaves within a tree become scarce the larvae will scatter in all directions in search of a new host. In a diverse plant habitat numerous non-host plants exist and larvae may have difficulty locating a suitable host. Larvae searching for additional foliage in a black walnut plantation need only find the next tree. Thus resource concentration may help to reduce dispersal related mortality. The walnut caterpillar has many characteristics of an eruptive species, thus occasional outbreaks should be expected. Walnut caterpillars pupate in the soil during late summer, thus manipulation of ground vegetation may provide opportunities for management of this defoliator.

The walnut shoot moth is the most destructive shoot borer on black walnut. Females deposit single eggs on the undersides of walnut, hickory or pecan leaves in early summer. The young larva feed on the lower epidermis of the leaves on which they hatch. In late summer, the larva constructs a hibernacula, located at the base of terminal bud or lateral buds, in which to overwinter. The larva emerges from the hibernacula at bud swell and feeds on the expanding bud. The larva bores into the elongating shoot and tunnels through the pith thus destroying the shoot. The mature larva leaves the shoot and pupates in the soil (Kearby 1979, Martinat and Wilson 1979). This herbivore possesses qualities of both latent and eruptive species. The larval food source is chosen by the female and larvae disperse only to a nearby bud and shoot. Unlike

the curculio, however, the plant modules utilized by the shoot moth, leaves, buds and shoots, are in abundant supply. Establishment of black walnut in plantations creates an unlimited food supply. However, Kearby (1979) suggested that total shoot loss in a black walnut plantation due to the shoot moth may be only 1 to 5% a year. While the annual incidence may remain low, deformity due to shoot die back may permanently reduce the value of the tree.

Piercing-sucking insects, such as scale insects and aphids, insert their mouthparts into the vascular tissue of twigs and feed on the vascular fluids. The oystershell scale is one such insect and it has many of the characteristics of an eruptive species. Eggs are deposited and overwinter under the adult female scale. They are separated by time and space from the larval feeding site. First instar larvae, called crawlers, disperse to new host trees and attach themselves to a twig on a suitable host. The scale has a wide host range including many fruit and hardwood trees grown in forests or as ornamentals. Heavy infestation can lead to branch dieback. Many piercing-sucking insects have characteristics of eruptive species and occasional outbreaks should be expected.

The life history characteristics of an insect herbivore determines it ability to rapidly increase in abundance and thus its capacity to attain outbreak densities. The spatial and temporal occurrence of outbreaks is greatly influenced by biotic and abiotic factors such as parasitoids and predators, climatic conditions and resource availability (quantity) and quality. Resource concentration in the form of black walnut plantations will influence host plant-insect interactions. The implications for management of insects feeding on black walnut is not always obvious. Understanding the impact of resource concentration on insect herbivores, and the biological interactions between insect life histories and plantation management practices should facilitate pest management decisions in a plantation landscape.

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FUSARIUM CANKER AND FREEZE INJURY OF BLACK WALNUT

Edward M. Hayes and Cynthia M. Ocamb[1]

ABSTRACT.—The winter of 1993-1994 caused some of the most serious injury ever witnessed by forest managers to southeast Minnesota and southwest Wisconsin black walnut plantations. It was estimated that five to six walnut plantations in each of five southeast Minnesota counties were severely injured. Severe injury was 75% to 100% of the walnut trees in a plantation sustaining more than 50% dieback. Topographic position appears to be the most important factor influencing injury. The type of sites that sustained the most injury were those valley sites with steep adjacent side slopes and bottomland sites where the walnut was planted in the lowest part of a broader landscape. Freeze injury occurred in both plantations and natural stands. Walnut trees wounded by the freeze injury were invaded by the fungus *Fusarium* spp. Adjacent noninjured walnut were not infected by *Fusarium* spp. We found *Fusarium* spp. were found to be opportunistic on walnut and frequently entered wounds created by the freeze injury.

FUSARIUM CANKER

Fusarium cankers of black walnut are elongate, annual cankers of various lengths that occur on the main stem and occasionally on the branches. Cankers first appear as cracks in the bark or expanded sunken areas. Loose bark will often cover the stained or diseased wood below. Infected trees may produce sprouts anywhere on the main stem or at the root collar. Cankered trees may die the same year cankers appear or may recover, though the tree survives with the internal defect.

Kessler (1974) first isolated *Fusarium lateritium* and *F. oxysporum* in 1974 from black walnut cankers in Illinois. Fusarium canker of black walnut was first reported in Minnesota in 1980 (Anonymous 1980). In that year two bottomland plantations in Wabasha and Fillmore counties were found to be heavily cankered, the result of lateral pruning conducted during the previous growing seasons. The recommendations for lateral pruning of black walnut subsequently changed to pruning only during the late dormant season. Pruning of black walnut is no longer recommended from April 1 to December 1, in Minnesota (Anonymous 1980). In 1984, *Fusarium sporotrichioides* was identified as causing the annual cankers on black walnut trees in both southwest Wisconsin and southeast Minnesota (Cummings and Kuntz 1986). In 1987, *Fusarium solani* was isolated from trees in Kansas (Tisserat 1987). Pathogenicity of all of these *Fusarium* spp. have been shown on walnut seedlings in greenhouse studies (Cummings and Kuntz 1986, Kessler 1974, Tisserat 1987).

1989 COOPERATIVE FIELD SURVEY

A cooperative survey was conducted in 1989 on the incidence of Fusarium canker in walnut

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plantations in Illinois, Iowa, Minnesota, Missouri, and Wisconsin (Carlson *et al.* 1993). A total of 19,340 trees were surveyed in 183 plantations, 90 on upland and 93 on bottomland sites. Fusarium canker was present in all five states. Thirty percent of all cankers were associated with some type of wound, with pruning found to be the most common. However, 70% of the cankers were not associated with any identifiable type of wound. Six species of Fusarium were isolated from cankers, with *Fusarium solani* the most common species found.

Significantly more walnut canker occurred on bottomland sites than on upland sites. Cankers associated with frost cracks or possibly other frost related injury were more prevalent on bottomland sites than on upland sites. There were significantly more cankers on the south side of all the trees. Also there were significantly more cankers on walnuts growing on southern and western aspects than on northern and eastern aspects on bottomland sites. Ninety-five percent of the cankers were located on the main stem.

1994 AND 1995 FUSARIUM ISOLATIONS

During 1995, black walnut trees exhibiting crown die-back in three different Minnesota plantations were sampled for presence of *Fusarium* spp. in the margin between the live cambial tissue and the dead necrotic area. In early May, the bark was peeled back from trees with dieback, exposing the discolored tissue on the main stem. Small pieces of cambial tissue were excised from the edge of necrotic areas as well as from healthy, non-discolored tissue. These small segments of tissues were disinfected in 95% ethanol for 1 minute and then embedded into solidified pentachloronitrobenzene-peptone agar (Nash and Snyder 1962) supplemented with Aureomycin (Nash medium) (Kommedahl *et al.* 1979). Cultures on Nash medium were incubated at 24°C with indirect lighting up to 21 days.

Identification of *Fusarium* spp. was done by transferring colonies to PDA and CLA then incubating the cultures under fluorescent lamps (three General Electric or Sylvania 40W tubes) supplemented with black light (one Sylvania 40W tube, BLB series) for a 12-hour photoperiod at 25°C (Nelson *et al.* 1983). Each isolate was examined microscopically and classified as to species according to the system of Nelson, Toussoun, and Marasas (1983). No *Fusarium* spp. were isolated from apparently healthy tissue, however *F. solani* was isolated from the cankered tissue (Table 1).

In August 1994, two trees were sampled from two different Minnesota plantations both injured by the freeze injury. *Fusarium* spp. were found again at the edge of the necrotic areas, (Table 1) but not from adjacent non-injured trees.

FREEZE INJURY

Winter injury or freeze injury to black walnut in Minnesota was first reported in 1984 (Anonymous 1984). In that year, general winter injury was widespread on conifers and hardwoods. Winter injury to walnut was subsequently reported in 1988, 1990, 1991, and 1994, (Anonymous 1988, 1990, 1991, 1994). In 1994, the injury was widespread across southeast Minnesota with similar reports of injury from southwest Wisconsin (Prey *et al.* 1994) and northeast Iowa (personal communication, Iowa Department of Natural Resources).

Black walnut is very susceptible to freeze injury of the xylem and pith tissues (George *et al.* 1974, Burke *et al.* 1975). Black walnut, along with four other hardwood species, were evaluated throughout their natural ranges and were found to attain a cold hardiness limit in the vicinity of -40°C, below which freeze injury occurred. Field collections of twigs were exposed to low temperatures under laboratory conditions. The xylem and pith of walnut was injured at -37°C when collected from southern sources and at -43°C for northern sources. No samples remained uninjured below -43°C. These results did not indicate the overall cold-hardiness of walnut throughout its natural range, but do indicate the maximum hardiness the species can attain during the midwinter months. Throughout the range of walnut there will be considerable variation in the timing of cold accumulation or deaccumulation which is dependent on the latitude and the average annual minimum temperatures reached in that region. This study, however, shows an important threshold of low temperature below which we can expect to see dieback and mortality in black walnut plantations.

Table 1.—*Fusarium* spp. isolated from the margin between live and dead tissue in black walnut with dieback during 1994 and 1995 field surveys

Year	Site	Tree	Tissue sampled	*Fusarium* species found
1994	1	1	cankered	*F. proliferatum* *F. oxysporum*
	2	1	cankered	*F. proliferatum* *F. oxysporum*
1995	3	1	cankered	+
		2	cankered	-
		3	cankered	*F. solani*
	4	1	cankered	-
		2	cankered	*F. solani*
		3	cankered	*F. solani*
	5	1	cankered	*F. solani*
		2	cankered	*F. solani*

+, Identified as *Fusarium*, but not to species.

-, No *Fusarium* sp. found.

Winter injury was reported in a 10-year-old black walnut provenience study designed to evaluate the survival, growth, and winter hardiness of black walnut (Bey 1979). Several states were involved in the study, including Minnesota, with one plantation located in Winona county. Following the extremely cold and dry winter of 1976-1977, the Missouri and Kansas plantations sustained severe winter injury. Crown dieback and mortality was related to origin of the seed. Injured trees in both the Missouri and Kansas plantations were from southern seed sources. Subsequent recommendations for collection zones were, in-part, based on the winter injury (Bey 1979).

1994 PLANTATION SURVEYS

In Wabasha and Goodhue counties of Minnesota, 36 state land plantations on both upland and bottomland sites were surveyed in the summer of 1994 for freeze injury. Walnut in eight plantations (20%) showed freeze injury. The level of injury was either light or severe. Light injury was 10% to 15% of plantation with less than 25% crown dieback. Severe injury was 75% to 100% of plantation with more than 50% dieback. Three of the eight plantations had severe injury.

An example of severe injury was Goodhue county plantation T1-R112-S16. In this 18-year-old plantation, 70 trees per acre were dead and 70 trees per acre had 100% dieback with sprouting from the root collar. The remaining 110 trees per acre had from 76% to 99% crown dieback. It was estimated that five to six walnut plantations in each of the five southeast Minnesota counties were severely injured, with an estimated 30 to 40 more plantations sustaining light injury. Injury occurred in both plantations and natural stands.

1993-1994 WINTER TEMPERATURES

The records of the weather station at the Rochester airport show during the winter of 1993-1994 that there were three different periods of temperatures -28°C or colder. During January 13 to January 20, there were 5 days when temperatures ranged from -29°C to -34°C, followed by two extremely cold days in February (Fig. 1). In 1988, 1990, and 1991, there was a similar pattern of temperatures reaching -28°C or lower at Rochester and subsequent reports of winter injury to walnut.

The low temperatures recorded at the Rochester airport do not tell the whole story. During the 1994 cold spell when temperatures fell to -38°C

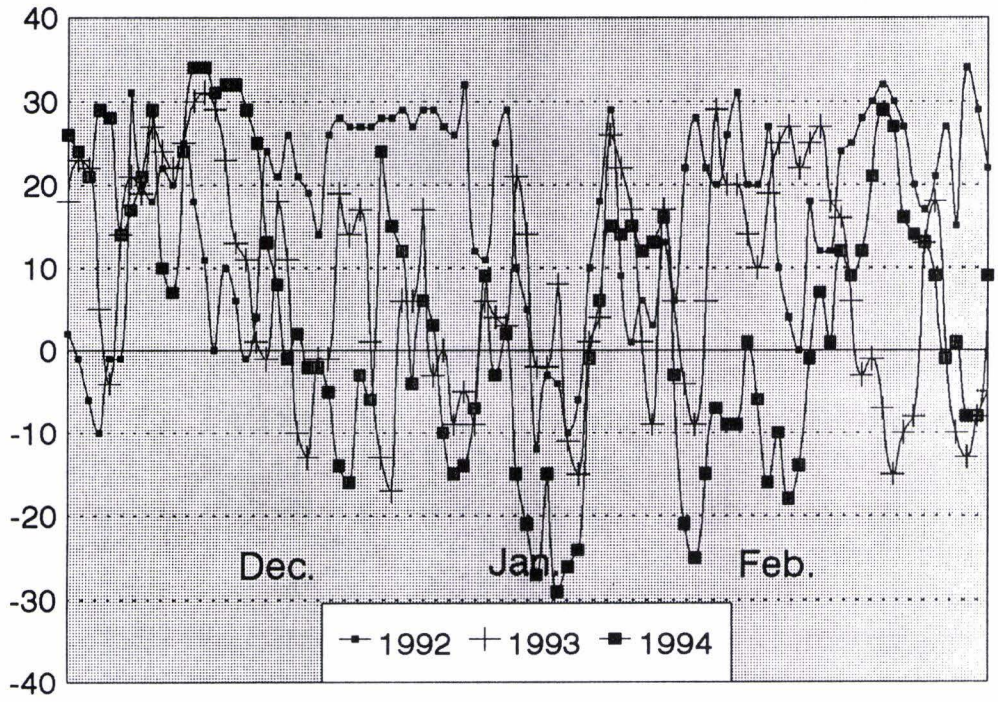

Figure 1.—Daily minimum temperature (°F) as recorded at Rochester, Minnesota for December through February of 1992, 1993, and 1994.

and -39°C on upland farm locations, temperatures in the adjacent bottomlands were another 10 to 15 degrees colder (personal communications, Tom McMillan, Wabasha county, MN, and Phillip Rutter, Fillmore county, MN). The temperatures in these bottomlands would be -44°C to -47°C easily surpassing the threshold lows that can cause freeze injury to black walnut.

DISCUSSION

FUSARIUM CANKER

In Minnesota during the 1994 field season, *Fusarium* spp. were isolated from walnut trees wounded by the 1993-1994 winter freeze injury, but not from adjacent nearby noninjured walnut. *Fusarium* spp. were found to be good opportunistic pathogens by entering the wounds created by the freeze injury. In 1995 in Minnesota, *Fusarium solani* was the most common *Fusarium* spp. isolated from the 1993-1994 freeze injured trees.

In the 1989 five state cooperative survey 30% of the cankers were associated with pruning wounds; however, 70% of the cankers were not associated with any type of visible wound. This raised questions about the presence of large numbers of undetectable wounds such as freeze injury or sunscald as well as the ability of *Fusarium* spp. to infect without a wound. Though *Fusarium* spp. are known to infect hosts without wounding, many pathogenic *Fusarium* spp. are considered opportunistic pathogens (Ocamb 1991), and the diseases they cause increase with wounding to the susceptible host (Palmer and Kommedahal 1969).

The vulnerability of black walnut to freeze injury and, perhaps, the undetectable wounds reported in the 1989 cooperative survey suggest that the extremes in micro-climate site conditions that exist in the central states may be playing a far greater role in the incidence of canker of walnut than has been realized up to this time. These reports now also suggest that *Fusarium solani* may be the most important *Fusarium* spp. causing the annual cankers of black walnut in the central states and the ultimate decline and death of black walnut severely injured by extremely low temperatures. However, it is possible that the *Fusarium* spp. may be entirely secondary. As

pointed out in the 1989 survey, its pathogenicity remains to be proven in the field (Carlson *et al.* 1993).

The only control for Fusarium canker is to avoid wounding. Since the early 1980's in Minnesota, Fusarium cankers on walnut have been associated with pruning wounds that were made during the growing season and on bottomland sites. In addition, new cankers originating at the sites of dead unpruned branches were observed to occur on bottomland sites but at a much lower incidence (Anonymous 1983). In the 1980's walnut plantations were successfully pruned during the late dormant season without resulting in new canker disease. This pruning took place in plantations with known Fusarium canker disease present and without any unusual efforts of sanitation (Anonymous 1984). Thus, sanitation has not been recommended as a control in Minnesota.

Selecting sites that decrease the exposure of black walnut to low temperature extremes may be the best course for avoiding Fusarium canker disease in Minnesota. This may be true for the entire tri-state area of southeast Minnesota, southwest Wisconsin, and northeast Iowa.

FREEZE INJURY

Topographic position appears to be the most important factor influencing the walnut freeze injury. The type of sites that sustained the most injury were those valley sites with steep adjacent side slopes and bottomland sites where the walnut was planted in the lowest part of a broader landscape. These types of sites are where the cold air is channeled through or can settle into, with little possibility of escape. Until now these were considered some of the best sites for growing black walnut in southeast Minnesota, but now should be considered high risk. Due to the topography and the periodic extremes of low temperatures, the thresholds for freeze injury are being reached. This combination of topography and low temperatures creates a microclimate which makes these sites high risk even though they are within the natural range of black walnut in southeast Minnesota (Fig. 2).

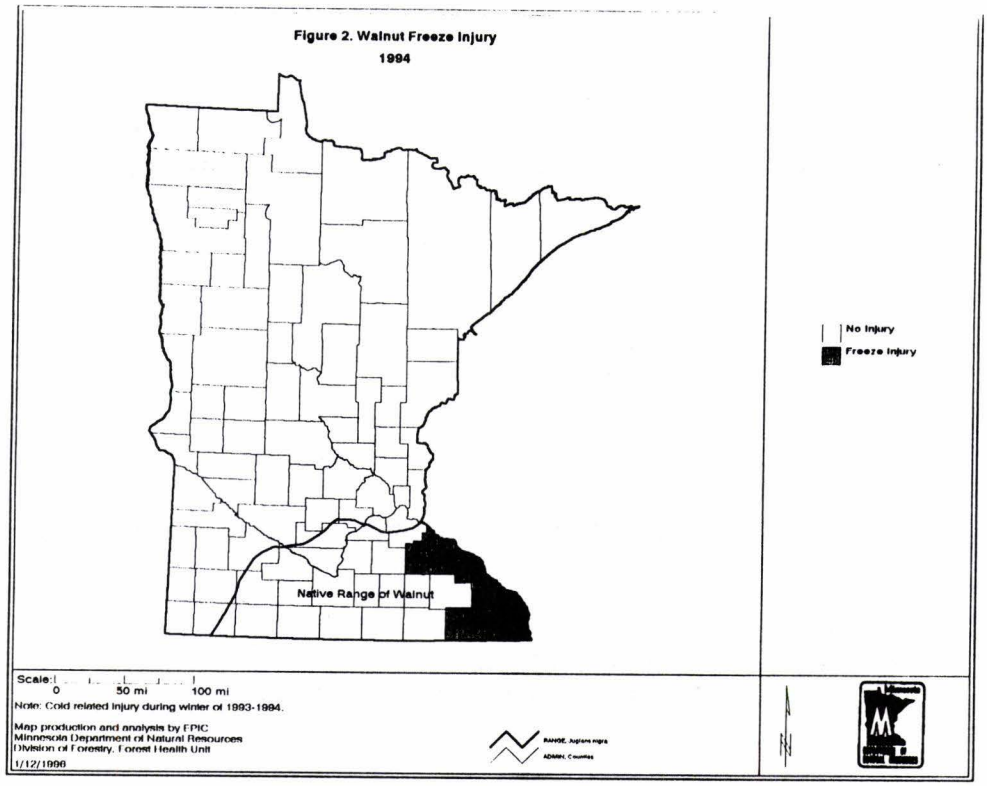

Figure 2.—Black walnut natural range and counties reporting freeze injury in 1994.

When freeze injury occurs in southeast Minnesota, there is wide variability where injury occurs and the extent of injury in plantations and to individual trees. Given the known genetic diversity of tree species, there may be injury in the most sensitive portion of the black walnut population that is exposed to less than injury-threshold low temperatures. These injury sensitive trees would account for much of the scattered light dieback that has occurred in bottomland plantations over the recent years (Anonymous 1980, 1982). In plantations severely injured in 1994, some trees survive without injury, representing individuals on the other end of the genetic spectrum.

Examination of weather data (Figs. 3 and 4) shows that in most years, the odds are great that these extremes of low temperatures can occur. In fact, the recent years appear more mild than the 1960's and 1970's.

Low temperature represents one of the most important environmental constraints on the productivity and distribution of plants on the earth. In fact, there is a good correlation between the northern boundary of 49 deciduous tree species in North America and the minimum temperature isotherm in which their winter-acclimated xylem can survive freezing (George *et al.* 1974). This temperature was found to be about -40°C for black walnut and several other hardwood species. Of course there are exceptions since certain species are found in areas where temperatures lower than -45°C are not uncommon. For example, *Ulmus americana* and *Fraxinus pennsylvanica* are both native to areas of northern Canadian provinces where temperatures lower than -45°C have been reported. Extremely hardy species of boreal deciduous trees such as *Salix*, *Populus*, and *Betula* survive freezing at -70°C or below. The threshold temperatures for injury to boxelder is around -60°C (Sakai and Larcher 1987).

Winter survival is a complex response and many other factors may influence this response. These may include genetics, stage of growth, site productivity as it relates to its influence on the accumulation or deaccumulation of the trees to low temperatures, and the previous seasons growing conditions.

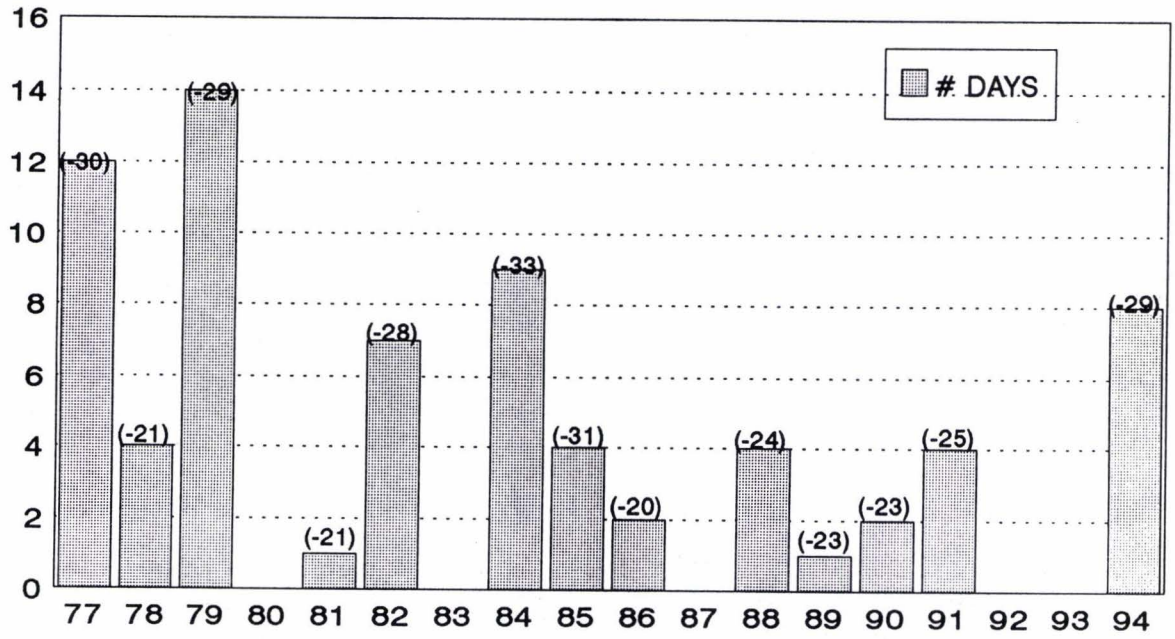

Figure 3.—The number of days the temperature reached -20°F or lower and the lowest temperature recorded at Rochester, Minnesota from 1955 to 1975.

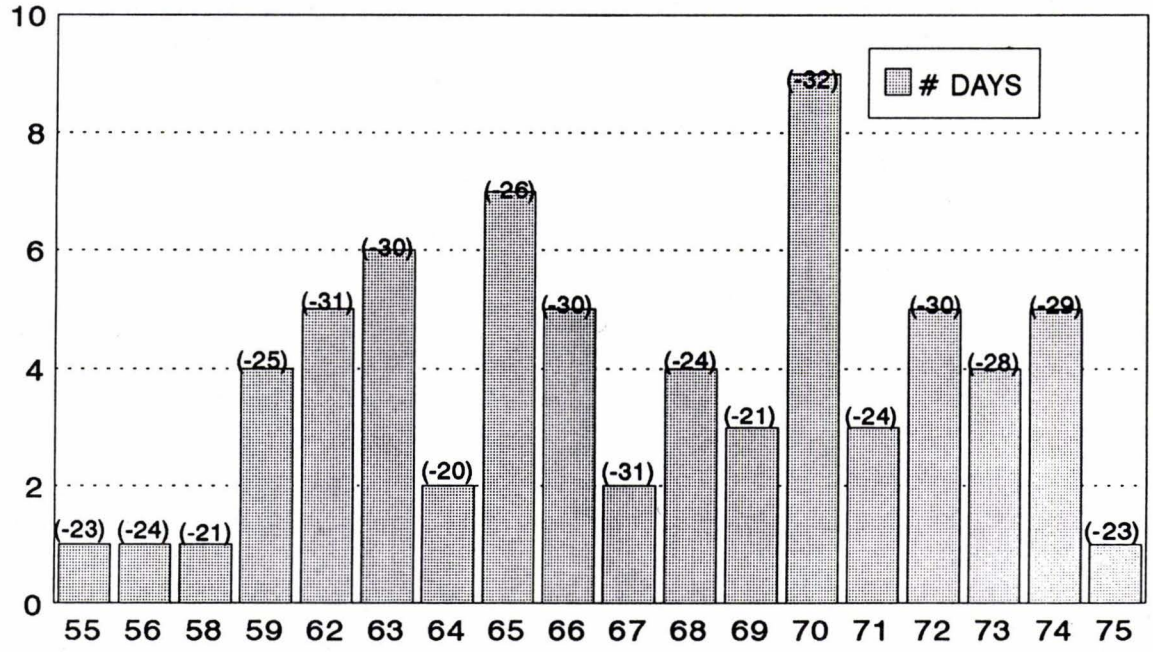

Figure 4.—The number of days the temperature reached -20°F or lower and the lowest temperature recorded that year at Rochester, Minnesota from 1977 to 1994.

SILVICULTURAL RECOMMENDATIONS

Suggested silvicultural recommendations for black walnut for southeast Minnesota, southwest Wisconsin, and northeast Iowa are:

- Restrict future walnut plantations to sites where walnut grows naturally or where walnut survived the 1994 winter;
- Avoid narrow valley bottoms with steep side slopes or sites in broad valleys that form the lowest elevation in the landscape; Continue to plant walnut on first bench or upland sites;
- Consider interplantings of other species with walnut;
- Continue to laterally prune walnut but only during the late dormant season, do not prune from April 1 to December 1;
- Select trees that demonstrate resistance to cold temperatures.

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BUTTERNUT CANKER: HISTORY, BIOLOGY, IMPACT, AND RESISTANCE

Michael E. Ostry[1]

ABSTRACT.—Butternut canker, caused by the fungus *Sirococcus clavigignenti-juglandacearum*, is killing butternut (*Juglans cinerea*) throughout its range in North America. First reported from Wisconsin in 1967, the disease has killed up to 80% of the butternut in some states. Healthy trees, and infected trees that apparently have resistance and survived the disease, have been found in severely affected forest stands. The USDA Forest Service and several states have established butternut harvest guidelines in an attempt to conserve the species. Clonal propagation of trees exhibiting resistance has been used to establish several clone banks to retain butternut genotypes for further research, and for breeding and future restoration efforts.

Butternut (*Juglans cinerea*) is valued for its wood for furniture, paneling, specialty products, carving, and nut production. It is also an important source of wildlife mast and significantly contributes to the biodiversity of forest stands. The range of butternut is similar to black walnut (*J. nigra*) but it extends farther north and not as far south (Rink 1990). Butternut is not a common tree anywhere within its range, but grows in several forest types with many other tree species.

Butternut canker, caused by the fungus *Sirococcus clavigignenti-juglandacearum* Nair, Kostichka & Kuntz, is killing trees throughout the range of butternut. In addition, butternut is relatively short-lived and shade intolerant, thus older trees of low vigor are declining even in the absence of the canker. Crown dieback, decay, root rot, and damage by wood borers are symptoms commonly associated with these trees. Because of these factors, the number of butternut trees have been dramatically reduced and it is listed under Category 2 on the list of Endangered and Threatened Plants under the Federal Endangered Species Act of 1973. This category implies that there is some evidence of vulnerability, but not enough data to support listing at this time.

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Questions have been raised as to why we should be concerned about the decline and premature mortality of butternut, an economically minor component of forest stands. Perhaps this quote taken from Graves (1923) in discussing the Melanconis disease of butternut is as pertinent today, if not more than when it was written. "*A botanist of some standing, in the course of a conversation with the writer about this disease, remarked that our country could well get along without the butternut. With the same line of reasoning one may argue that many of our native timber trees of secondary commercial importance may be dispensed with, and thus eliminate them, one by one. But we are losing all of our chestnut, a tree of the first magnitude; the white pine, the most valuable coniferous species in the Eastern United States, is seriously threatened. And because of the increasing scarcity of better woods many species formerly considered of minor importance, are coming into service, and have a constantly rising value. Certainly this policy of laissez-faire as voiced by our colleague, is greatly to be deplored and is diametrically opposed to the principal of conservation.*" Today we could add to this list several tree species that are being impacted by disease: American elm (*Ulmus americana*) by Dutch elm disease; oak (*Quercus* spp.) by oak wilt; American beech (*Fagus grandifolia*) by beech bark disease, and more recently flowering dogwood (*Cornus florida*) by dogwood anthracnose, and white ash (*Fraxinus americana*) by the ash yellows disease. Clearly,

we cannot afford to ignore the loss of butternut caused by butternut canker and the effect it has on the composition and diversity of our forests.

Several conservation groups, and state and federal agencies have formed a coalition to conserve as much of the butternut resource as possible, and to restore it to a viable component of the ecosystem (USDA Forest Service 1995a). The distribution of butternut crosses many forest types and ownerships. Cooperation of many people is essential in this endeavor, and significant progress has been made in bringing interested individuals together to achieve these goals.

DISEASE DESCRIPTION

HISTORY

Butternut decline, common throughout northeastern United States in the early 1900's, was characterized by branch dieback, colonization by the fungus *Melanconis juglandis* Ellis & Everhart) Graves, and gradual death of trees (Graves 1923). No cankers were associated with affected trees. The decline and death of butternut trees continued to be attributed to the infection by *M. juglandis*, or its imperfect state (*Melanconium oblongum* Berkeley), until a reported observation in southwestern Wisconsin in 1967 of dieback and, for the first time, a stem canker of butternut (WI Con. Dep. 1967). In this brief report it was stated that a survey of a 40-acre woodlot revealed that all but two butternut trees had cankers. This evidence, and detailed examinations of canker ages (Nicholls 1979) indicates that butternut canker has been present in the United States at least since the early 1960's, perhaps much earlier.

It was not until 1979 that the true cause of butternut canker was reported to be a newly described fungus *Sirococcus clavigignenti-juglandacearum* (Nair *et al.* 1979). Its origin remains unknown, but several lines of evidence indicate that this is a recently introduced fungus. Factors relating to the fungus and to the disease partially supporting this assertion are: apparent rapid spread of the disease throughout the butternut range since its discovery; the highly aggressive nature of the disease on infected trees; the relative scarcity of resistant trees; the lack of genetic diversity in the fungus (Unpublished data of G.R. Furnier, M.E. Ostry, and A.M. Stolz, Department of Forest Resources, University of Minnesota); and the age of the oldest cankers (40 years) examined in North Carolina (Personal communication, R.L. Anderson, USFS).

DISTRIBUTION AND SYMPTOMS

Surveys of butternut to determine their health are difficult owing to the highly scattered nature of the occurrence of trees in many forest types. However, the disease has been detected throughout the range of butternut in North America. The disease was first reported from Ontario, Canada in 1992 (Davis *et al.* 1992) where it was said to be common. It was stated in this report that the disease had also been recorded in Quebec. The disease has not yet been reported in the Maritime Provinces, and efforts are underway to confirm this and to prevent the entry of the fungus, particularly into New Brunswick where a population of healthy butternut still exists (Personal communication, L.A. Cree, Agriculture and Agri-Food Canada).

Young cankers are elongated, sunken areas commonly originating at leaf scars and lateral buds, usually in the upper crowns. Later, cankers develop an inky black center with a whitish margin resulting from tissue degradation by the fungus. Removal of the bark reveals the brown to black elliptical area of killed cambium. Small branches are rapidly killed, resulting in dieback and symptoms similar to the Melanconis disease. The fungus *M. juglandis* invades and is often found on branches killed by *S. clavigignenti-juglandacearum*, contributing to the past misidentification of the cause of butternut canker. Most stem cankers become perennial, and are often found in bark fissures or under the bark. Stem cankers commonly occur on the lower stem and on exposed root flares where old cankers become target shaped, caused by the layers of callus that surround each canker.

DAMAGE AND IMPACT

Butternut canker kills trees of all ages. Branches and young saplings may be quickly killed by a single canker, although, older trees are killed over a period of time by multiple, coalescing cankers that either progressively kill the crown or eventually girdle the stem. Sprouts, if they develop, also become infected and are killed usually within the first few years. Thus, unlike American chestnut (*Castanea dentata*)

sprouts affected by chestnut blight that still attain a fairly large size, butternut genotypes affected by butternut canker are rapidly being lost.

Analysis of USDA Forest Service forest inventory data indicate a dramatic decrease in the number of live butternut trees in the United States in the last 15 years. Live butternut in all size classes combined decreased by 58% in Wisconsin and 84% in Michigan during this period. These data do not distinguish healthy from diseased or declining trees. In 1978 butternut canker had not been reported in Vermont or New Hampshire (Anderson and LaMadeleine 1978), but since has been observed throughout those states. In 1976 butternut canker was present only in southwestern Wisconsin where it was found on 80% of the trees examined (Prey *et al.* 1982). A recent Wisconsin Department of Natural Resources survey revealed that 91% of the live butternut in all age classes throughout Wisconsin were diseased (Carlson 1993). Surveys in the southeast United States revealed that 77% of the butternut have been killed in North Carolina and Virginia, and infected trees continue to be found in new counties in most of the northeast and north central regions (USDA Forest Service 1995b). More importantly, surveys have indicated a decline in the health of butternut, with reproduction generally limited to fence rows, and old pastures where it is often infected. For these reasons butternut has been listed as rare, or as a sensitive species of special concern in many states.

FUNGUS BIOLOGY

There is no known sexual state of *S. clavigignenti-juglandacearum*. Asexual spores (conidia) develop under infected bark in sticky masses where stromatal pegs break open the bark and the conidia are dispersed by rainsplash and wind during rainfall throughout the growing season. Conidia are only released during rainfall, in small droplets or as aerosols (Tisserat and Kuntz 1983a). Large numbers of conidia are carried in runoff water down tree trunks from branch cankers into wounds and other openings, causing multiple stem cankers. Spores can travel at least 150 ft in rainsplash (Nicholls 1979).

Infection of young branches in the crown usually precedes stem infections. The fungus infects trees through buds, and openings such as lenticels and bark cracks. Another common entry is through leaf scars (Kuntz *et al.* 1979). The fungus continues to sporulate on standing or felled dead trees for at least 20 months (Tisserat and Kuntz 1982, 1984) so unless entire infected trees are removed from the stand, local sanitation by felling trees is not effective.

Cool, cloudy weather favors spore longevity and conidia can survive for at least 8 hours under these conditions (Tisserat and Kuntz 1983b), indicating the possibility of long distance spread. Since the number of airborne conidia rapidly decreases from an inoculum source (Tisserat and Kuntz 1983b, Nicholls 1979) it has been speculated that birds or insects may be involved in the long distance spread of the fungus required to infect isolated and widely scattered butternut.

There is evidence that *S. clavigignenti-juglandacearum* can be seedborne. Butternut seedlings were killed soon after emergence from seed collected from infected trees, stratified with intact husks, and sown in a greenhouse (Orchard 1984). The fungus was isolated from lesions at the base of the seedlings where they were attached to the seed. If the fungus is commonly seedborne, early infection and death of seedlings could partially explain the lack of butternut regeneration, and increases the possibility of spread of the fungus on nursery stock. Recently, butternut canker was identified on nursery seedlings in Quebec (Personal communication, Gaston Laflamme, Canadian Forestry Service). Butternut seed had been collected throughout Quebec and planted in a nursery located away from any native butternut trees. The fungus was isolated from lesions at the base of the stem near the point of attachment to the seed. Another *Sirococcus* species, *S. conigenus* (DC.) P. Cannon & Minter is known to be seedborne on some *Pinaceae* species.

The North Central Forest Experiment Station, with cooperation of Northeastern Area State and Private Forestry, initiated a study in the spring of 1995 to examine the potential role of insects in the infection of trees by *S. clavigignenti-juglandacearum* and its dissemination. Several plots were established in Minnesota and Wisconsin to monitor insect activity in healthy and infected butternut trees. These sites were visited several times throughout the year and collections of insects were made for identification and for laboratory examinations to detect if the insects

were carrying the fungus on or in their bodies. Sample trees were examined for evidence of oviposition or feeding wounds that may serve as entry courts for the fungus.

Literature sources list 117 insect species and one mite species associated with butternut (Table 1). The vast majority were in three insect orders: Lepidoptera (51 species), Coleoptera (37 species) and Homoptera (20 species).

Table 1.—Insect orders, number of families, and the number of species reported in literature sources as being associated with butternut

Insect order	Famlies	Species
	Number	
Coleoptera	9	37
Diptera	2	2
Hemiptera	2	3
Homoptera	5	20
Hymenoptera	3	3
Orthoptera	1	1
Lepidoptera	15	51
Totals	37	117

Field collections in 1995 in Minnesota and Wisconsin found 34 species associated with butternut (Table 2). This number is incomplete since a number of collected specimens have not yet been identified to species, including a large collection of Lepidopteran caterpillars (Unpublished data of Katovich and Ostry, USFS). Identified species have been placed into a reference collection for use in this project.

Table 2.—Insect orders, number of families, and the number of species collected in association with butternut trees in Minnesota and Wisconsin in 1995 (Identifications not completed)

Insect order	Famlies	Species
	Number	
Coleoptera	10	27
Diptera	1	1
Hemiptera	1	1
Homoptera	3	3
Lepidoptera	1	2
Totals	16	34

On recently dead branches of butternut, a group of small beetles were commonly found under bark in association with the stromatal pegs and pycnidia produced by *Sirococcus*. This group of beetles included five different families, Laemophloeidae, Monotomidae, Nitidulidae, Phalacridae and Staphylinidae. Many of these have been previously reported in association with fungi and the habitat under tree bark, but none have been previously reported specifically on butternut or associated with butternut canker. *Sirococcus* was isolated in pure culture from the following three species; *Laemophlaeus fasciatus, L. testareus* (Laemophloeidae), and *Bactridium* spp. (Monotomidae). We have not yet attempted isolation from any of the other insect species that we have collected.

HOST RANGE

Butternut is the only species significantly damaged by this disease. Black walnut has infrequently been found infected naturally in the field when growing with severely diseased butternut (Kuntz *et al.* 1979). The fungus has not been recorded on any other tree species growing in mixed stands with butternut.

Using artificial inoculations, Orchard *et al.* (1982) assessed the relative susceptibility of several commercially valuable *Juglans* species and hybrids to *S. clavigignenti-juglandacearum* in 10- to 20-year-old field plantings near Carbondale, IL. Species included black walnut, Persian walnut (*J. regia*), Japanese walnut (*J. ailantifolia*) and heartnut (*J. ailantifolia* var. *cordiformis*), and various hybrids of these species. All of these species and hybrids are susceptible to some degree. Japanese walnut, heartnut, and hybrids between them and butternut exhibited greater resistance to the fungus, developing smaller cankers, than either Persian walnut or black walnut.

To determine if hardwoods other than species of *Juglans* could be infected, and perhaps provide a source of inoculum in forest stands, 12 potted 1-year-old seedlings each, of 9 hardwood species: white ash (*F. americana*), green ash (*F. pennsylvanica*), pecan (*Carya illinoensis*), shagbark hickory (*Carya ovata*), white oak (*Q. alba*), northern red oak (*Q. rubra*), black oak (*Q. velutina*), bur oak (*Q. macrocarpa*), and black cherry (*Prunus serotina*) were wound-inoculated with mycelium or spores from one of two isolates

of *S. clavigignenti-juglandacearum* in the greenhouse and scored for disease development. Black walnut and butternut seedlings were included for comparison. All of the butternut were nursery seedlings from seed of unknown origins.

After 3 months, the greatest canker expansion was on butternut, followed by black walnut and shagbark hickory (Ostry, Unpublished data). Canker development was greater on butternut when mycelium was used than when spores were used as the inoculum, but cankers were larger on black walnut when spores were used. A few butternut seedlings were girdled by elongating cankers, and on some seedlings much larger cankers developed than on the others. This may indicate variation in disease susceptibility among seedlings. Non-inoculated control wounds on all species were completely callused-over and no canker symptoms developed.

The majority of inoculated wounds on all of the species other than black walnut, butternut, and shagbark hickory were callused-over. However, the wood directly beneath the inoculated wound, and slightly beyond the wound margin on many of the species was stained indicating infection by the fungus. The fungus was re-isolated from these areas on inoculated pecan, shagbark hickory, black cherry, red, black, and white oak.

These results suggest that the fungus might be able to survive on hardwoods other than butternut by causing either inconspicuous cankers, or rapid death (a hypersensitive reaction) of small branches, similar to inoculated black walnut (Orchard 1984). We did not detect sporulation on any of inoculated seedlings after 3 months. We plan to repeat this experiment with the seedlings under more favorable conditions for spore production than were present in this trial. Greater effort will be made in future field studies to determine if species other than butternut are hosts and, if so, what importance this would have in the etiology of this disease.

CONTROL

There is no known control for butternut canker. Even if there was, the widely scattered nature of the occurrence of butternut in native forests would make control impractical. Sanitation to remove recently killed or severely infected trees may reduce inoculum in local areas, but until we learn more about the long distance spread of the fungus by birds or insects its long-term effectiveness is unknown. Fungicides have been tested in the laboratory with some success but they have not been applied to trees in the field, and would only be practical in nurseries or high value plantations (Nicholls 1979).

DISEASE RESISTANCE

Currently there are no known cultivars or varieties of butternut in commercial trade with proven resistance to butternut canker since many of them may have been selected for various traits such as nut production in the absence of the disease. Limited research has been directed at screening butternut selections for resistance. In work determining optimum conditions for screening, succulent butternut seedlings from open-pollinated healthy and diseased parents were inoculated with spores in growth chambers and later examined for infection (Orchard *et al.* 1981, Orchard 1984). All of the seedlings became infected, although after 12 weeks canker development was significantly greater on seedlings from diseased parents. Although these results are preliminary, they suggest that resistance to butternut canker may be heritable.

Genetic improvement to develop resistance in butternut is justified if individuals exhibiting disease resistance can be found and propagated. Interspecific breeding with *Juglans* species and varieties such as Japanese walnut and heartnut that have greater canker resistance than butternut may also be a strategy that can be employed to obtain superior trees for reforestation and for nut production in plantations.

IDENTIFYING RESISTANT TREES

Occasionally, a few healthy butternut growing among diseased and killed trees have been found. Although these trees may be "escapes", it is more likely that they may have resistance to the disease. Some of these trees are canker-free in spite of growing directly alongside severely diseased trees. Other trees have few cankers, or they may have cankers that have been completely closed-over by callus, a host response suggesting possible disease resistance or tolerance. These trees may be able to live many years with the disease. Trees that are free from stem cankers may have infected branches, making it

difficult to select potentially resistant trees with a high degree of certainty without closely inspecting the upper crowns. Although young branch cankers have developed in the crowns of a few of our field-selected trees, the majority have remained disease-free since first being selected.

The distribution of this disease throughout the range of widely scattered butternut is good evidence that the fungus is easily disseminated so healthy trees growing near diseased trees probably have been exposed to the fungus. Criteria have been developed to assist land managers and woodlot owners interested in identifying butternut that may have disease resistance and may be valuable for tree improvement efforts (Ostry *et al.* 1994). Trees are permanently tagged, measured, their location mapped, and information on their health and the health of adjacent butternut are noted.

At the end of the 1995 season, we had a total of 148 trees from 14 states in our collection (WI, MN, IA, NH, NC, WV, MI, MO, VT, NY, CT, ME, KY, PA). Of these, 31 were known to be diseased when scionwood was collected, or they have become diseased since they were first located. Some of these trees were chosen because of their apparent high susceptibility and value for use as controls in inoculation experiments. Others were chosen because they exhibited a resistance, or tolerance response characterized by cankers surrounded by callus or being completely callused-over.

In addition to our research to conserve potentially resistant butternut, a cooperative effort to locate and propagate surviving butternut in the southern Appalachian region was established in 1992 (Personal communication, S.E. Schlarbaum, University of Tennessee). Seed was collected from butternut in the Great Smoky Mountains National Park and from southern Tennessee and North Carolina. Seedlings were planted in several test plantings to evaluate their disease resistance. An open-pollinated progeny test and clonal propagation of selected individual trees for the establishment of a breeding orchard are planned.

PROPAGATION AND CLONAL ARCHIVE PLANTINGS

Our goal is to clonally propagate butternut with putative disease resistance and good form from locations throughout the range of butternut in the United States. Scionwood from selected healthy, mature trees is collected in February and early March for bench grafting in March. Side grafts using lateral and terminal buds on flushed black walnut rootstock in the greenhouse has worked well for us with most selections (Barker and Ostry, manuscript in preparation). In 1995 grafting success among the various accessions ranged from 0 to 85%. Some trees have grafted well each year but others have been difficult.

There is an immediate need to collect and preserve butternut selections for future breeding and restoration efforts. Aside from the butternut canker disease, butternut with potential canker resistance is rapidly being eliminated from forest stands. Causes range from root disease, old age, harvest, weather damage, and changing land use. Reproduction is often scarce, caused by periodic low seed production, consumption of seed by animals, lack of stump sprouts, and the absence of necessary site conditions for seedling establishment and survival.

With the assistance of many cooperators in locating healthy trees and collecting scionwood from them for grafting, work towards restoring butternut was started in 1989. In 1992 the first outplanting of grafted butternut selections was established near Rosemount, MN. Since then, we have added four additional replicated plantings; at the Oconto River Seed Orchard on the Nicolet National Forest in WI; the Tree Improvement Center near Carbondale, IL; the Hancock Seed Orchard on the Green Mountain National Forest, VT; and the New York State Seed Orchard near Saratoga Springs, NY. The objective of these plantings is to serve as a clone bank to: (1) preserve valuable butternut genotypes, (2) become sources for obtaining scionwood for disease research and for possible future seed orchard establishment, and (3) allow in situ evaluation of each selection for such traits as growth, stem form, flowering, and disease resistance.

RESISTANCE SCREENING

A major goal of our research is to evaluate the butternut selections that we have collected for their canker resistance. We are developing a technique that accurately distinguishes resistant and highly susceptible individuals. Previous

researchers inoculated young, succulent seedlings in greenhouses or growth chambers to study disease development. It remains to be shown if inoculations of juvenile tissues accurately reflects host responses in mature trees. We will soon be able to inoculate clonal lines of butternut propagated from severely diseased and healthy trees to determine for the first time if juvenile-mature correlations exist for canker resistance.

We would like to develop a disease resistance screening procedure that could be applied in a greenhouse to save the expenses associated with field tests. However, disease results from a complex set of interacting host, pathogen, and environmental factors. Resistance and susceptibility of individual butternut trees may only be accurately expressed under natural field conditions or conditions that closely mimic them. Our research is directed at filling the gaps in our knowledge of this disease so that we can duplicate these conditions.

MANAGEMENT GUIDELINES

The premise of this research was that if something was not done to conserve butternut soon, it would be too late. Potentially resistant butternut were rapidly being lost, and there were no efforts to encourage butternut retention and regeneration. Land managers were, in fact, discriminating against butternut because of the disease, in some instances harvesting all butternut in the belief that the disease would eventually kill them.

Butternut is shade intolerant and must be in the overstory to thrive. We have proposed some suggested management guidelines for land managers and woodlot owners who are interested in maintaining butternut as a component in their stands (Ostry *et al.* 1994, 1996). In addition to retaining potentially resistant butternut for seed production, proper seedbed preparation, light availability, and control of competing vegetation must be provided for seedling survival and growth.

Butternut grows in association with many forest types across many land ownerships. Restoration and management of this species will require cooperation of land owners and managers, and an ecological approach to be successful.

CONCLUSIONS

We cannot as yet answer with a high degree of certainty the question of whether or not effective resistance or tolerance to butternut canker exists among surviving butternut. Evidence from field surveys certainly suggests that resistance is present but not common. Characteristics of the disease, including the apparent rapid spread of the pathogen throughout the range of butternut in North America, and the high incidence of butternut mortality indicates this may be an introduced pathogen. If this is the case, the prospects of finding resistance among native populations of butternut may be difficult because the species has not had time to develop resistance to the disease.

However, finding healthy and recovering butternut growing among severely diseased trees is encouraging. If, after artificial challenge with the fungus, and in situ screening, these trees prove to have adequate levels of disease resistance they could be used for breeding and clonal propagation to re-introduce butternut to areas where the disease has eliminated the species. Since we have not detected the fungus on other species in forest stands, after susceptible butternut are killed, it may be possible to plant selected resistant butternut or butternut hybrids back into forests where butternut was once an important component.

Butternut is being eliminated from our forests from multiple causes. Butternut canker, however, is threatening the existence of viable populations of butternut across most areas of its range. We have the advantage of using the lessons learned with beech bark disease, Dutch elm disease, and chestnut blight. There may still be time to bring techniques of gene conservation (Ledig 1988) to bear on efforts to retain butternut in our forest ecosystems.

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AGROFORESTRY PROGRAMS IN THE TEMPERATE ZONE

W. J. Rietveld and H. Gene Garrett[1]

ABSTRACT.—An agroforestry display and information for distribution were featured in the exhibit area of the Fifth Black Walnut Symposium to draw attention to the growing interest in agroforestry in the temperate zone of the United States. According to a 1995 survey conducted by the National Agroforestry Center, there are currently 32 agroforestry programs in the United States, each involved in some combination of research, teaching, and extension. The majority of the agroforestry effort resides in university programs (29) with the remainder in federal agencies. Private organizations that promote agroforestry were not included in the survey. The majority of the programs are fledgling efforts involving only one or two faculty members; only five agroforestry programs represent a substantial effort. All the programs recognize agroforestry as an emerging technology that has significant untapped potential to increase productivity and sustainability within agricultural and forestry land-use systems. The Association for Temperate Agroforestry (AFTA) has played a key role in helping to organize the agroforestry effort in the United States. They have sponsored biennial North American Agroforestry Conferences in Guelph, Ontario; Springfield, Missouri; Ames, Iowa; Boise, Idaho; and the 1997 conference to be held in Ithaca, New York. The AFTA has also published several key policy papers on agroforestry opportunities and needs and has encouraged the establishment of regional associations to promote information exchange. The National Agroforestry Center in Lincoln, Nebraska is a partnership of USDA agencies created to provide leadership and promote partnerships for development and application of agroforestry programs nationwide.

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ALLEY CROPPING CORN TO ESTABLISH BLACK WALNUT IN INDIANA

Hugh B. Pence and Judy A. Pence[1]

ABSTRACT.—We describe our agroforestry project testing the concept of alley-cropping corn during the establishment of our 114 acre black walnut planting. In addition, we give a few recommendations we would make if we did it all over again.

Our black walnut planting was started in 1988 by purchasing average quality farmland, but excellent quality land for walnut, along the Wildcat Creek near Lafayette, Indiana. Our primary motivation was to produce high-quality veneer logs while keeping our on-going costs to a minimum by alley-cropping corn between the tree rows. The annual cash crop would help with the farm payments and plantation expenses after the walnut planting was established.

Our initial inquires for information showed that little was known about the nutritional needs for walnut trees. Because we knew how to grow corn, we decided on a fertilization program based on growing corn. We divided the 114 acre site into 45 2.5 acre plots. Soil samples were taken from each plot to determine the amount of lime needed to raise pH to 6.5 to 6.8 and recommended amounts of nitrogen (N), phosphorus (P), potassium (K), and trace elements to produce 150 bushel to the acre corn. Depending on the chemical analysis, from 0 to 5 tons of lime were added to each plot along with recommended amounts of NPK and trace elements.

Our farm tenant planted the entire farm in 1988 to corn the first year we owned the farm using a 30 in. corn planter. In the spring of 1989, using the 1988 corn rows as a guide, we planted 44,000 walnut seedlings purchased from the Indiana State Nursery approximately 5 ft apart in every ninth row. Thus, tree rows are 22.5 ft apart. This allowed us to leave an empty row on either side of the walnut seedlings and to still run a 6-row corn planter between the tree rows. The close spacing within rows was used so that we could begin thinning early in the rotation to select for straight, fast-growing walnut trees and remove any damaged or diseased trees.

Since 1989, we have annually applied recommended rates of NPK and trace elements for corn production to the entire area. In 1991, we added an additional 2 tons of lime per acre to the entire farm. Over the years, weed control for both the walnut and corn has included various combinations of simazine, atrazine, glyphosate, and Dual, and 2,4-D. Until 1996, we grew corn every year between the tree rows. Because of decreased corn yields resulting from disease problems created by growing corn continuously in a no-till environment, we converted to soybeans in 1996. This fall we will probably switch to winter wheat on half the planting and oats next spring on the other half. By splitting the crop, we can work on the half to be planted to oats this winter to do our usual extensive lateral pruning and thinning of the walnut trees. We will continue to work towards reducing our number of trees to approximately 200 trees per acre.

Eight years after establishing the walnut, 85% of the trees are 20 to 30 ft tall with 3 to 5 in. stem diameters. This fall we will mark each tree showing good nut production with a blue band of spray paint. We plan to annually mark the best nut producers using a different color each year. At some future time when the stem diameters reach 9 to 10 in., we will harvest approximately 60 trees per acre further reducing our stand of trees to 140 trees per acre. We plan to keep the best nut producers and the best potential veneer trees. When the trees reach stem diameters of

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14 in., we will do our final thinning of another 60 to 70 trees per acre as sawlogs or small veneer logs. Thus, we should end up with 70 trees per acre for the final rotation harvest.

The walnut trees in areas with more poorly drained soils and/or droughty soils have grown slower and have poorer form. In some areas, 2 to 5% of these trees show symptoms of bunch disease and are being removed. We do not know if the high incidence of bunch disease is associated with tree stress, high levels of chemical weed control, or spreading of the disease by pruning equipment because these trees required more corrective and lateral pruning than the trees on the better sites.

Over this 8 year period, we have made a number of observations and recommended changes for this type of agroforestry project. During the first 2 to 3 years, the corn served as tree shelters protecting the walnut seedlings from the wind. The corn also provided a trainer effect by casting sufficient side-shade to produce tall, single stemmed walnut saplings. The high fertility kept the trees growing late into the fall and in many years, the leaves were green until the first killing frost. Pruning during the dormant season has become a full time job to remove lateral branches from the lower 1/4 to 1/3rd of the tree, to remove permanent forks, and to correctively prune the 3 to 5% of trees with blown out tops that occur each year.

During the first few years, the expected losses in corn yield from using three corn rows for a row of trees were partially offset by increased yields in corn rows 1 and 6 (outside rows) adjacent to the walnut trees. We planted regular corn in 1989 and 1995; waxy corn in 1990, 1991, and 1992; and amylose corn in 1993 and 1994. We received a 35 cent per bushel premium for waxy corn and a 55% premium for amylose corn. Corn yields in bushels/acre averaged 165 in 1989, 180 in 1990, 43 in 1991 (extreme drought), 100 in 1992, 65 in 1993, 113 in 1994, and 40 in 1995 (another drought and some bad seed varieties). The soybeans yielded 38 bushels to the acre, a more than acceptable yield for our area of Indiana in 1996.

We tried to reduce root competition by applying our nitrogen as anhydrous nitrogen and running the application knife 8 in. deep between the trees and the outside rows of corn. By the fifth year (1994), however, corn yields in the rows adjacent to the walnut rows began to decrease from competition for light and soil moisture. If we had to do it over again, the one change we would make would be to have the rows 37.5 to 40 ft apart—sufficiently wide for a 12-row corn planter and a 12-row sprayer—and greatly improve the efficiency of the farming operation.

BIOLOGY AND ECONOMICS OF A BLACK WALNUT-CORN ALLEY CROPPING SYSTEM

Shibu Jose, Tamara Benjamin, Tyra Stall, Andrew R. Gillespie, William L. Hoover, David B. Mengel, John R. Seifert, and Donald J. Biehle[1]

ABSTRACT.—Black walnut alley cropping, a production system in which walnut trees are established in hedgerows with agronomic crops cultivated in the alleys, is becoming a popular agroforestry practice in the Midwest. Although black walnut agroforestry systems are widespread in the Midwest, little work has been undertaken on the tree/crop interactions. The objective of the present study was to explain the temporal reductions in corn yields in a walnut alley cropping system on the basis of above and belowground competitions for available resources. It was hypothesized that corn growth and yield would be more adversely affected by aboveground competition for light than belowground competition for moisture and nutrients. Our study was carried out in a black walnut/corn alley cropping system established in 1985 at the Purdue University Southeastern Agriculture Center near Seymour, Indiana. In 1995, three treatments were applied corresponding to (1) trenching with plastic barrier, (2) trenching only, and (3) no trenching. Microenvironmental and physiological measurements were collected along with growth and yield measurements. Avoiding root competition between walnut and corn resulted in an average yield increase of up to 62%. We conclude that below-ground competition for water and/or nutrients may be more important than above-ground competition for light.

INTRODUCTION

Alley cropping, a production system in which trees and/or shrubs are established in hedgerows on crop land with agronomic crops or pasture grasses cultivated in the alleys, has been a subject of numerous experiments in the tropics. A number of mutually beneficial interactions between tree and crop components have been postulated. For example, fertilizers and herbicides applied to crops can be utilized by trees in the hedgerows. Also, crop production may be enhanced through micro-environmental modification by tree rows as well as mulching by tree litter. Thus, in order to develop successful alley cropping systems, it is important to have an understanding of the relationships between the planted trees and crops. Along with biological viability of such systems, economic feasibility should also be given consideration.

In recent years, interest in diversifying farm income and reducing environmental impacts of agriculture has led to the development of alley cropping systems in the temperate region. In the United States, systems combining crops with timber producing trees, especially black walnut (*Juglans nigra* L.) have been established on several sites in the Midwest (Garrett and Kurtz 1983, Kurtz *et al.* 1984, Noweg and Kurtz 1987, Bandolin and Fisher 1991, Williams and Gordon 1992, Rule *et al.* 1994). With the Central Hardwood Region's continuing shift of timber management from public to private lands, and the importance of farm woodlots in the production of fine hardwoods for forest industry, alley cropping can provide an additional farm income while conserving soil and water resources, aiding pest control, and reducing fertilizer inputs.

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Although considerable research has been done on the 'tree component' of alley cropping systems, little work has been undertaken on tree/crop interactions and seasonal environmental resource sharing patterns and limitations. Hence, the objective of the present study was to explain the temporal reductions in corn yields in a walnut alley cropping system based on microenvironmental modifications by tree rows and resulting crop physiological responses. It was hypothesized that corn being a C4 plant, aboveground competition for light might be more important than below-ground competition for water and nutrients.

MATERIALS AND METHODS

STUDY AREA

The study was carried out in an alley cropping system with corn and black walnut, established in 1985, at the Purdue University Southeastern Agriculture Center near Seymour, Indiana. The experimental site includes a randomized complete block design with 12 plots. The spacing between tree rows is 27 ft (intra row spacing of 8 ft) and six rows of corn are planted within the alley with a north south orientation. The soil is a Parke Silt Loam, a well-drained loess over loamy glacial till, underlain by sand and gravel. This soil has moderate permeability and high water holding capacity, with the subsoil extending to 175 cm.

In the spring of 1995, the following three treatments were applied randomly to each of the four blocks:
— Treatment 1 (Barrier): Root pruning along with below ground partition, where polyethylene strips, 120 cm deep, are installed on both sides of the tree rows at a distance of 4 ft to avoid below-ground competition between trees and corn for soil moisture and nutrients.
— Treatment 2 (Trench): Root pruning only, where roots were pruned on both sides of tree rows at a distance of 4 ft to a depth of 120 cm.
— Treatment 3 (Control): Neither root pruning nor partition were applied.

MEASUREMENTS

Corn yield (bushels per acre) by row was collected for the years 1986, 1987, 1988, 1993, and 1995. All microenvironmental and physiological measurements were made during the growing season in 1993 and 1995 (data presented in this paper are from 1993 measurements). One corn plant was selected in each first, third, and sixth row from the east. Net photosynthetic rate, transpiration, and stomatal conductance were measured on these plants using a portable infrared gas analyzer (ADC Ltd., London). Photosynthetically active radiation (PAR, 400-700 nm), relative humidity, and air and leaf temperature were also monitored. Further, during the 1995 growing season, mid-day and pre-dawn leaf water potential for walnut and corn were measured using a pressure chamber (PMS Instruments Inc., Corvallis, OR).

Tree growth and corn yield data for the past 11 years were incorporated into an economic model. Both the expenses and income were included in a financial analysis using discount rates of 3, 5, and 8% (Gann 1996). A growth rate of 0.5 in. in diameter per year was assumed for the walnut trees with a rotation length of 60 years. "Predicting Black Walnut Log Prices" (Hoover, 1995) was used to determine the prices for walnut logs from intermediate thinnings and final harvest.

A separate economic model was constructed for the agroforestry system by including and compensating for any known biological interactions. Corn was assumed to be grown an extra 10 years between the tree rows. This was possible given that dew data show trenching or disking the site reduces competition for water resources between the trees and crops. The two models were compared to determine the higher overall financial returns.

RESULTS AND DISCUSSION

TEMPORAL REDUCTION IN CROP YIELD

Although first and second year (1986 and 1987) corn yields were higher than the normal farm average (106% and 107%, respectively) yield started decreasing in the third year. Among different rows, first and sixth rows had the highest yield until 1988 (Fig. 1). The higher yield of the outer rows compared to that of the middle rows can be explained on the basis of increased light availability, and less competition for moisture and nutrients. However, by 1993 yield from the outer rows was significantly lower than the middle rows. It is evident that competition for

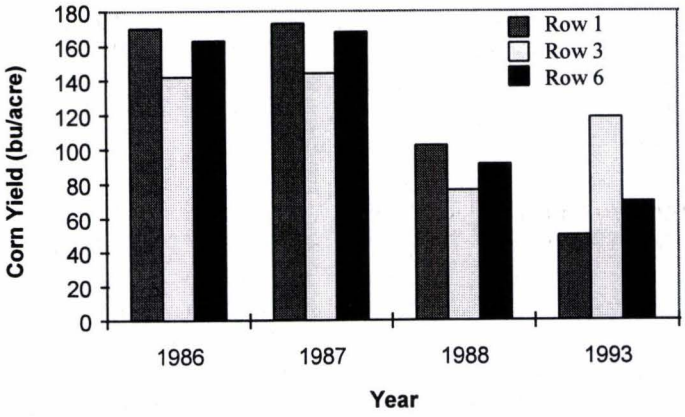

Figure 1.—Temporal reduction in corn yield from 1986 through 1993.

the available resources between the trees and crops was much more severe and the outer rows were adversely affected.

LIGHT AVAILABILITY WITHIN THE ALLEY

Although daily average incident photosynthetically active radiation (PAR) between rows was not significantly different, the middle row had the highest average (Table 1). Diurnal measurements of PAR revealed that the middle row receives the maximum sunlight during any given time of the day (Fig. 2). The incident radiation on the outer rows depends on the north-south orientation of the alleys. During early mornings, the eastern row (first row) is shaded the most and the western row receives as much sunlight as the middle row. This pattern is reversed by afternoon with the eastern row receiving greater amounts of PAR than the western row. However, incident radiation is uniformly distributed on all the rows during midday. Temperature measurements followed a similar pattern as that of PAR.

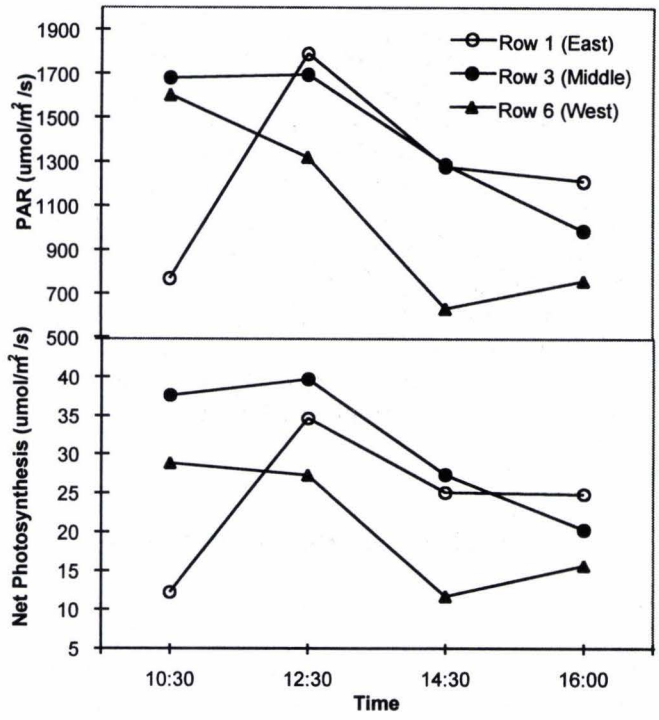

Figure 2.—Diurnal pattern of incident PAR and net photosynthesis in different corn rows.

PHOTOSYNTHESIS

Diurnal photosynthesis followed the same pattern as incident PAR (Fig. 2). The middle row of corn showed the highest photosynthetic rate during any given measurement period (except 16:00 hr measurement). In general, photosynthetic rate was lower during the morning and evening measurements, with the peak rate being observed during mid-day.

It is not surprising to observe the same diurnal pattern for PAR and photosynthesis. As shown in Figure 3, PAR and photosynthetic rate in corn

Table 1.—Average daily photosynthetically active radiation (PAR), net photosynthesis (Pnet), water use efficiency (WUE), and yield for different rows of corn for the year 1993

Row No.	PAR (μmol $m^{-2}s^{-1}$)	Pnet (μmol $m^{-2}s^{-1}$)	WUE (μmol CO_2 /mol water)	Yield (bu $acre^{-1}$)
1	1,262.7 a [1]	24.19 a	7.98 a	49.76 a
3	1,412.4 a	31.25 a	7.95 a	118.29 b
6	1,078.0 a	20.85 a	7.93 a	69.57 a

[1] Column means followed by the same letter are not significantly different according to Duncan's Multiple Range Test, alpha=0.05.

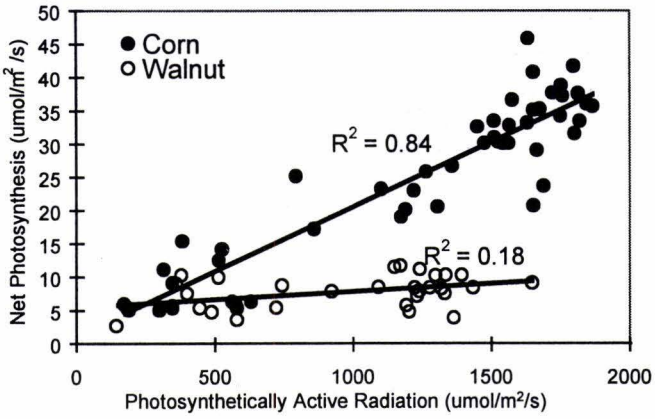

Figure 3.—Photosynthesis in corn and black walnut as related to PAR.

are strongly correlated. Being a C4 plant, corn is not light-saturated even at a PAR of 1400 µmol $m^{-2}s^{-1}$. However, black walnut photosynthesis has reached its peak near a PAR of 500 µmol m^{-2} s^{-1}. Considering average daily photosynthesis, no significant differences were observed between rows, although the middle row had the highest rate of photosynthesis.

TRANSPIRATION, STOMATAL CONDUCTANCE, AND WATER USE EFFICIENCY

In general, rates of transpiration and stomatal conductance were higher for the middle row as compared to the outer rows (Fig. 4). Higher incident light on the middle rows, and probably higher water availability in the middle of the alley may be responsible for this phenomenon. Water use efficiency (WUE) was calculated as the ratio of net photosynthesis (Pnet) to stomatal conductance because this represents a more consistent estimate of the relative WUE than does the ratio of Pnet to transpiration (Meinzer *et al.* 1990). From Table 1 it is evident that no significant differences were observed between the rows for their water use efficiency.

CORN YIELD IN 1995

The three different treatments applied in spring 1995 had considerable influence on corn yield (Fig. 5). Plots with plastic barriers had an average yield of 98.7 bushels per acre whereas trenching resulted in a similar yield of 100.4 bushels per acre. Control plots had the lowest yield of 61.4 bushels per acre. Thus, avoiding

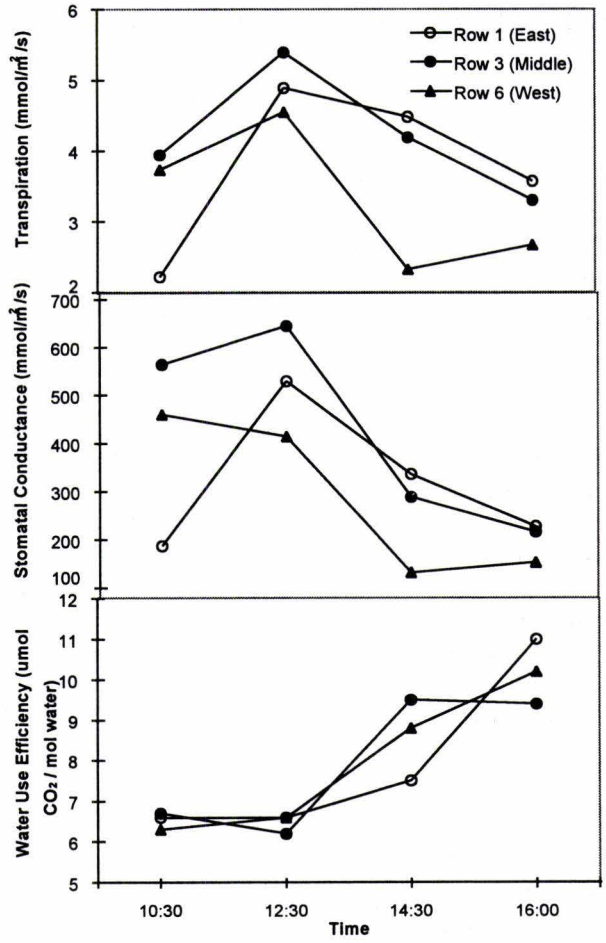

Figure 4.—Diurnal pattern of transpiration, stomatal conductance, and water use efficiency in different corn rows.

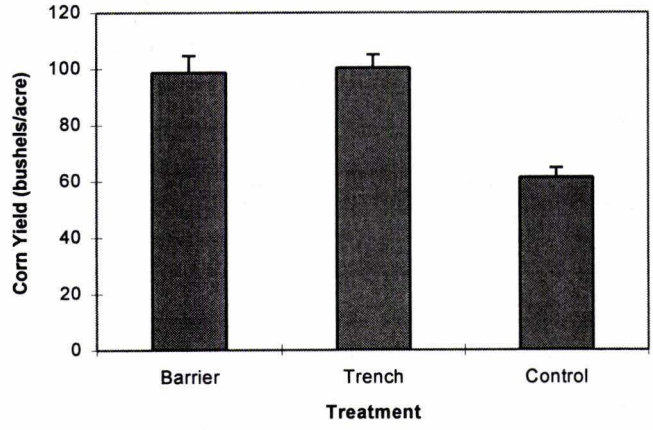

Figure 5.—Corn yield (1995) in three different treatments.

Table 2.—Mid-day and pre-dawn leaf water potential (MPa) for walnut and corn during July 19, 1995

Treatment	Walnut		Corn			
	Mid-day	Pre-dawn	Mid-day		Pre-dawn	
			1st row	3rd row	1st row	3rd row
Plastic barrier	-1.87	-0.44	-1.29	-1.18	-0.18	-0.20
Trench only	-1.75	-0.42	-1.22	-1.26	-0.27	-0.23
Control	-1.71	-0.36	-1.41	-1.36	-0.21	-0.20

root competition between black walnut and corn resulted in an average yield increase of 62% over the control. It is apparent that below-ground competition for water and nutrients was much higher in the control plots where tree roots were allowed to interact with corn roots. Root pruning avoided competition for soil water and nutrients at least in the top 4 ft. As revealed in Table 2, mid-day corn leaf water potentials for control plots were higher than for either barrier or trenched plots, indicating water stress in control plots.

Similar results have been reported from the tropics where polyethylene barriers or root pruning resulted in a higher yield of the agronomic crop (Singh *et al.* 1989, Ong *et al.* 1991 Korwar and Radder 1994). Competition for soil moisture was responsible for the negative interactions in these semi-arid systems.

Kang (1993) suggested that root pruning, if done early and repeated periodically by tilling the alleys, can reduce the number of hedgerow roots in the plow zone and force tree roots to deeper levels. In a temperate zone study, Ssekabembe *et al.* (1994) found that using a below-ground partition between black locust alleys resulted in a soil moisture depletion of up to 32% in the hedgerows. Kuhns *et al.* (1985), while studying root growth patterns of black walnut, concluded that root growth and number of growing roots decreased sharply as soil water potential changed from -0.5 to -1.0 MPa. Ongoing studies on root production within the hedgerows and alleys will give insight into these aspects. However, the present data give some indication of water stress in the hedgerows during the day. Mid-day walnut leaf water potential (Table 2) was lower in the barrier as well as in the trenching treatments (-1.87 MPa and -1.75 MPa, respectively) relative to the control plots (-1.71 MPa). Limiting walnut rooting volume within the hedgerows might be responsible for this phenomenon.

Apart from below-ground competition for soil moisture and nutrients, the possibility of juglone phytotoxicity exists in walnut intercropping systems. Research is currently underway to examine the influence of juglone on corn growth and physiology.

ECONOMIC MODELING

In preliminary economic modeling, results have shown an increase in potential financial returns through use of system biological interactions. The additional years of corn production offset the added costs of disking or trenching the site and increased net present value. The longer time frame of land utilization for cropping increased the financial returns to the farmer. Although the known biological interactions are helpful in constructing meaningful economic models, more data are needed to develop a more accurate picture. For example, the impact of disking or trenching on tree volume has not been quantified, though existing unpublished data at Purdue indicate little effect. Also, 10 years of additional corn production is an hypothesis. To create a more precise economic model, information is needed for all interactions. Answers are needed to questions such as how growth and yield of various crops are affected over time, and when it will be necessary to alter cropping systems given the interacting influences of soil and site, tree dynamics, crop characteristics, and financial markets.

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GROWING HIGH-VALUE CROPS UNDER BLACK WALNUT

Bill Slagle and Elsie Slagle[1]

ABSTRACT.—Production of high-value crops under black walnut can be highly profitable; however, it requires advanced planning and can be both labor intensive and risky. In our report, we describe some of the advanced planning, equipment, risks, and labor needed to grow ginseng in mixed hardwood forests and black walnut plantations.

In 1985, we decided to expand our ginseng operation and try raising this shade-tolerant crop under the shade of a managed black walnut plantation. We knew ginseng required deep, well-drained soils similar to walnut for good growth and was even less tolerant of water saturated soils than walnut. To improve the drainage on some poor farmland, we created a series of terraces, or raised beds, approximately 12 ft apart on 10 acres of hayland. The ridges were created using a rented tractor and 4-bottom plow. Two furrows were plowed together twice to create the ridges. We direct seeded nuts approximately 1.5 ft apart along the ridges with the intention to begin thinning almost immediately to remove poorly formed trees. We laid down plastic mulch along the walnut seedlings for weed control. On part of the area to provide a cash crop, we planted vine crops such as cantaloupes and pumpkins on the plastic within the tree rows.

By 1990, the trees had been thinned to an irregular spacing of 6 to 8 ft apart, and tree crowns within the rows had closed. We tilled 4 to 5 ft wide beds under the trees and sowed ginseng seed. Previous experience had convinced us that sowing ginseng seed was better than transplanting ginseng seedlings. The drought of 1990 resulted in poor ginseng seedling survival in some areas especially those with the highest clay content. In the spring of 1991, we had to spray the 20 to 30 ft high walnut trees every 5 days to prevent gypsy moth larvae from defoliating the walnut trees. If we had not, we would have lost both the shade-tolerant ginseng and the young walnut trees. In other years we have had problems with slugs killing the ginseng due to the moist environment created under the trees.

Proper management of ginseng under walnut has been a labor intensive operation requiring a modest investment in farm equipment. We use mostly hand tools and a 35-HP tractor. In addition, we have a three-point hitch mounted two bottom plow, rototiller, four tooth harrow, and scraper blade (for diversion ditches). Getting the beds ready for planting takes the most effort, except for possibly harvesting the ginseng roots. Preparing 2.5 acres of our 6-acre planting took approximately 5 weeks with the help of two high school students. Maintaining the ginseng beds is also a labor intensive operation, requiring hand-weeding for the first 2 years. We estimate it required two people approximately 10 days per season to hand-weed the beds. Pests must continually be controlled. It takes two people 2 to 4 days per month to do the spraying from early May to early October. Although rewarding, harvesting ginseng from under high-value trees can also be labor intensive. We estimate it will take 4 to 5 weeks for five people to dig by hand one acre of ginseng roots.

After seven or eight growing seasons, we expect the ginseng roots to be of sufficient age to begin harvesting them. Based on previous harvests, we expect yields of between 800 and 1,200 pounds per acre. This yield would be 25 to 35%

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of what we normally harvest in our mixed hardwood stands where the entire forest floor is seeded with ginseng. The price of ginseng roots depends on age and quality. We now recommend planting oak acorns with the walnuts to provide a denser shade for growing high-quality ginseng. Wild ginseng has sold for between $250 and $350 per pound for the last 2 years. The market price for a 6- to 7-year-old cultivated roots is approximately half that of wild ginseng. The price for ginseng roots is based on the neck, where the growth rings show the age and growth rate. We expect to harvest most of our ginseng as 10- to 12-year-old roots and obtain a price comparable to wild ginseng. With proper management, we expect to manage on an 8-, 10-, 12-year cycle of harvesting rather than selling 5- to 6-year-old roots as we have for the last 15 years.

We believe we have demonstrated that the production of high-value crops under walnut, as well as in our native hardwood forests, can be done profitably; however, it requires constant and continual effort for 6 to 12 years to benefit from your planning, labor, and risk-taking.

EVALUATION AND MANAGEMENT OF BLACK WALNUT FOR NUT PRODUCTION

William Reid[1]

ABSTRACT.—The potential of eastern black walnut as a nut producing tree crop has been recognized for over a century. Although over 700 cultivars have been named for their nut producing ability, large scale production data for any walnut clone are nonexistent. Important cultivar characteristics needed for commercialization of black walnut are known and are present in many of the best cultivars available today. The advancement of black walnut as an orchard crop will require the induction of annual seed production. Alternate bearing has been minimized in other nut tree crops with the application of standard horticultural practices. The response of black walnut to intensive management should be evaluated. Once annual nut production is induced, producers must learn techniques for managing nut feeding insects and/or crop load (reducing over-production). A protocol for evaluating black walnut cultivars under a high level of management is proposed.

INTRODUCTION

Eastern black walnut (*Juglans nigra* L.) is an under-developed crop. The value of black walnut as a nut producing tree has been extolled ever since the discovery and propagation of 'Thomas' in 1881 (Corsa 1896). Yet little progress has been made in the domestication of this North-American, native tree. Today, black walnut remains one of the few food crops on the U.S. market that still relies on collections from the wild. Over 700 cultivars of black walnut have been selected from the wild, primarily by walnut enthusiasts (Reid 1990). However, little production data are available for any cultivar. In addition, management systems required to make black walnut a profitable orchard crop have not been developed.

BLACK WALNUT CULTIVARS

The selection and development of black walnut cultivars have been the passion of amateur nut growers. As a result, hundreds of cultivars of black walnut have been described (Berhow 1945, 1962; Milde *et al.* 1983) yet only a few are widely propagated. Today's popular cultivars share two important cultivar characteristics—outstanding nut quality and a tendency toward regular nut production. The average wild black walnut tree produces nuts that are difficult to crack and hold kernels tightly within shell fragments. Trees that produce thin shelled nuts that release kernels in large pieces have been highly prized and are often named solely on the basis of these characteristics. However, only the most productive of these outstanding nut producers have survived the test of time.

Limited information is available concerning black walnut cultivar performance. The majority of reports cite nut quality parameters (nut size and percent kernel) and give anecdotal evidence of productivity, precocity, and disease resistance. The cultivars described below are among the most widely propagated in the Midwest. Many of these could provide the foundation of commercial black walnut orchards.

IMPORTANT BLACK WALNUT CULTIVARS

'Emma K' is a seedling walnut originally found in Illinois. Nuts average 16.2 g and contain 35%

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kernel. Nuts have an elongated shape that may lend them to more efficient methods of mechanical cracking. Nuts are borne on lateral branches.

'Football' originated in S.W. Missouri as a seedling of a named cultivar. Nuts average 19.6 g and produce 30% kernel. Trees are very productive at a young age and bear fruit on lateral branches. This cultivar is very susceptible to anthracnose.

'Kwik-Krop' was discovered growing near El Dorado, KS. Nuts have a distinctive shape—pointed at both ends with a deep depression along the suture on the distal end of the nut. Nuts weigh 17.4 g and yield 31% kernel. As the name implies, 'Kwik-Krop' is precocious and bears fruit laterally.

'Sparks 147' was selected by Archie Sparks in Beaver, IA. The nuts produced by this clone have very thin shells. Nuts average 18.4 g and contain 38% kernel. A long, sharp point on the end of the nut makes cracking this nut somewhat difficult. Nuts production is fairly consistent. Fruit are borne laterally.

'Sparrow' was discovered in 1935 near Lomax, IL. This cultivar is a regular producer of medium sized nuts weighing 16.8 g and yielding 29% kernel. Sparrow has above average resistance to anthracnose.

'Surprise' was found among a row of seedling walnuts growing in S.W. Missouri. The seed source for 'Surprise' is unknown but seeds originated in Pennsylvania from an orchard of improved cultivars. The large nuts produced by this cultivar average 19.9 g and produce 34% kernel. Fruit are borne on lateral branches. 'Surprise' is moderately resistant to anthracnose.

'Thomas' was discovered near King of Prussia, PA in the 1870's and was first offered for sale in 1881. 'Thomas' has been the most widely propagated cultivar in North America and is the standard used to compare all other cultivars. 'Thomas' produces nuts weighing 19.7 g, but these easily-cracked nuts yield only 24% nut meat. This cultivar is moderately susceptible to anthracnose.

IMPORTANT CULTIVAR ATTRIBUTES

The genetic potential of *Juglans nigra* as nut producing tree crop has hardly been tapped. All of the cultivars described above have been selected from the wild or are open pollinated seedlings of cultivars selected from the wild. Organized crop improvement programs have focused on improving the timber quality of *Juglans nigra* and not concentrating the genetic traits important for nut production into clonally propagated cultivars. Genetic traits that would lead to advances in a nut tree improvement program include: lateral bud fruitfulness, late leafing, resistance to the anthracnose fungi, *Gnomonia leptostyla*, (Fr.) Ces. & Not., precocity and productivity, and improved nut quality.

Lateral Bud Fruitfulness — The selection of clones that produce pistillate flowers on lateral buds has resulted in significant yield increases in Persian walnut, *J. regia* (McGranahan and Leslie 1990, Ramos *et al.* 1984). Lateral bearing Persian walnut cultivars tend to be more precocious and are better suited to high yielding, high density plantings. The lateral bearing characteristic is also found in black walnut (Sparks 1982). Black walnut trees exhibiting this characteristic have a profusion of short, spur type branches distributed along main scaffold limbs. With this growth pattern, both leaves and nuts are borne throughout the tree canopy resulting in increased yield potential.

Late Leafing — Black walnut is quite susceptible to freezing temperatures once growth begins in the spring. Entire shoots are killed by temperatures below -2° C. Female flowers are borne on the terminals of these frost tender shoots and a late spring frost can destroy all potential for nut production. Late leafing clones can avoid yield losses due to frost. Date of leafing in black walnut has a high degree of heritability (Kucera *et al.* 1974) but leafing dates for currently propagated cultivars are unknown. In addition to frost avoidance, late leafing black walnut clones may avoid infections by the walnut blight bacterium, *Xanthomonas campestris* pv *juglandis* in the same manner as late leafing Persian walnut cultivars (Forde 1975). Further, immature or expanding black walnut leaves have shown the greatest resistance to infection by the anthracnose fungus (Cline and Neely 1984, Funk *et al.*

1981), thus the late leafing characteristic may also contribute to anthracnose infection avoidance. The anthracnose fungus requires high humidity and moderate temperatures to infect walnut leaves (Neely 1978). Late foliating trees mature their leaves when conditions are generally warmer and drier, conditions that inhibit anthracnose infection.

Anthracnose Resistance — The anthracnose fungus attacks leaves, new shoots and fruit of the black walnut. Initial foliar infections begin shortly after full leaf expansion during extended periods of leaf wetness (Kessler 1984). The disease progresses rapidly in mid-summer and results in premature defoliation by late August. This premature leaf drop is one of the major causes of poor kernel fill (Reid 1986) and alternate bearing (Sparks 1979) in black walnut. Complete resistance to the anthracnose fungi has not been found although a wide range in susceptibilities exists (Beineke and Masters 1973, Berry 1960). The 'Thomas' and 'Ohio' black walnut cultivars have been noted for their anthracnose resistance, although both cultivars will contract the disease under conditions of high disease pressure (Berry 1960). Heritability for anthracnose resistance is high (Beineke and Masters 1973, Funk *et al.* 1981) indicating genetic gains in resistance to this devastating disease can be made.

Precocity and Productivity — High development costs for establishing a walnut orchard demand the planting of cultivars that bear large crops at an early age. Cultivars displaying lateral bud fruitfulness generally come into production well in advance of non-lateral bearing cultivars (Sparks 1982). The precocity and productivity of black walnut cultivars have not been studied but should be prime considerations in selecting new cultivars. If lateral bearing black walnuts are similar to lateral bearing Persian walnuts, first commercial yields should be expected in the fifth year after establishment. Mature orchards should be able to produce more than 2 MT/ha of hulled walnuts.

Nut Quality — Nut quality characteristics have been the primary focus of the evaluation of black walnut cultivars. Over 400 cultivars have been evaluated for nut weight and percent kernel (Zarger 1945, Berhow 1962). Nut samples are evaluated annually by many State nut growers associations (Reid 1990).

Shell thickness and structure are the most important determinant of percent kernel and nut crackability. The highest quality walnuts have a thin outer shell with no internal convolutions protruding into the nut meat. The inner shell partition between kernel halves should be very thin to allow easy removal of kernel pieces. Most thin shelled black walnut cultivars yield over 30% kernel.

Kernel quality and plumpness are strongly influenced by tree care and harvesting practices (Chase 1941), but with trees receiving optimum care, wide differences in kernel quality still exist between cultivars. High quality walnuts have light colored kernels with an absence of kernel veins. Dark colored or strongly veined kernels are associated with rancidity by consumers.

CULTURAL PRACTICES PROMOTE NUT PRODUCTION

Standard horticultural practices used for the culture of other tree nut crops should be used in the black walnut orchard. Black walnut trees typically produce nut crops at irregular intervals both in the wild and in agroforestry settings. Commercialization of black walnut as an orchard crop will require the induction of annual seed production. Flowering intensity and seed set are largely determined by the level of carbohydrates stored by the tree during the previous growing season (Wood 1991). Regular nut production can be induced by ensuring trees remain vigorous and healthy.

Sunlight, water, nutrients, and healthy leaves are the key ingredients for optimum carbohydrate accumulation in all tree crops. Adequate tree spacing is the primary method used for ensuring maximum sunlight penetration into the canopy of a nut orchard. Trees given full sunlight develop large crowns maximizing the nut bearing area. New black walnut orchards should be planted at a density similar to new Persian walnut orchards, 120 trees/ha. As trees grow and canopies begin to complete for space, the orchard must be thinned to maintain optimum exposure to sunlight.

The best sites for black walnut are deep, well-drained, alluvial soils. These soils provide trees a large reservoir of both available water and soil nutrients. If nut orchards are established on

prime river bottom sites in the humid east, supplemental irrigation is not often needed. These fertile soils also have the capacity to provide walnut trees with optimum levels of all soil nutrients except nitrogen. Nitrogen is the primary nutrient applied to nut tree crops. Annual application of 115 to 230 kg N/ha are typical for Persian walnuts and pecans (Goff *et al.* 1989, Ramos 1985). To induce annual cropping, black walnuts should receive at least 115 kg N/ha. Other nutrients should be added only if foliar analyses reveal mineral deficiencies.

Pest induced defoliation of nut trees can seriously reduce the quality of the current season's nut crop and inhibit flowering during the subsequent growing season (Worley 1979). Early defoliation caused by the anthracnose fungus is a perennial problem for all black walnut cultivars and may be the factor most limiting annual nut production. Control of this disease is not difficult with modern fungicides (Reid, unpublished); however, few fungicides are currently registered for use on black walnut. Recent changes in EPA registration policy may improve this situation. New crop protection products will be registered for crop groups. Eastern black walnut is part of the tree nut group and products registered for use on pecan, Persian walnut, and almond will become available for use on black walnut. With adequate disease control, the leaves of black walnut trees remain photosynthetically active until frost, maximizing carbohydrate accumulation.

Once nut production is stimulated, growers will note an increase in production problems associated with annual fruiting and/or excessive fruit set. Regular fruiting will result in an increase in nut feeding pests, such as the black walnut curculio, *Conotrachelus retentus*. Management strategies for this pest have been developed and control is not difficult (Reid 1993). Like many nut trees, black walnut will respond to favorable weather conditions by setting excessive fruit loads. Overproduction leads to poor nut quality during the current season and initiates a cycle of alternate bearing in subsequent years (Reid 1986). Excessive nut loads on black walnut trees can be reduced by using mechanical fruit thinning techniques developed for pecan (Smith *et al.* 1995).

STANDARDS FOR FUTURE RESEARCH

Large scale trials of existing black walnut cultivars are needed to establish the profitability of growing black walnut as an orchard crop. Two important questions must be answered. Will investments in intensive cultural practices result in increased nut production? And, which cultivar characteristics are most important in a commercial orchard situation?

One of the most frustrating aspects of reviewing the literature concerning black walnut cultivar performance is the realization that there are no standard cultural procedures employed to maximize nut production and nut quality. Trials of black walnut cultivars should be established under a cultural regime similar to those used for commercial pecan (Goff *et al.* 1989) and Persian walnut orchards (Ramos 1985). Once the trees begin to bear fruit, all of the important cultivar characteristics for each cultivar should be recorded utilizing standard methods.

EVALUATING NUT YIELD AND KERNEL QUALITY

The use of proper harvest methods will guarantee the greatest yield of both nut and cultivar data. Harvest dates for black walnut vary widely, from mid-August to mid-October. To accurately assess nut yield and nut quality for each cultivar, it is important to harvest, dehull, and clean nuts as soon as fruits ripen. Black walnuts achieve peak kernel quality and are ready to harvest when fruit husks begin soften (Reid 1992). A tree shaker should be used to remove nuts from the tree. Yields should be measured by determining both the total weight of dry nuts produced and the total kilograms of kernel produced. Standard nut quality parameters, including nut weight, percent kernel, and kernel color should be recorded.

EVALUATING TREE CHARACTERISTICS

Tree form and bearing habit should be noted for each cultivar. The initiation of fruiting on lateral branches is an extremely important characteristic that may determine yield potential for a cultivar. Cultivars that bear fruit laterally usually begin to grow fruiting spurs 3 to 5 years after grafting. In addition, tree growth form should be

noted. Trees with a wide angled branching habit are best equipped to support heavy fruit loads. Upright growing trees with narrow angled branches are more susceptible to limb breakage under heavy fruiting or high wind conditions.

The phenology of physiologically important events often determine a cultivar's ability to withstand environmental stress. Late leafing cultivars avoid spring frosts. Early ripening cultivars may be more susceptible to sun scald but less prone to drought stress. Important physiological events include: leaf burst, flowering, shell hardening, kernel filling, and fruit ripening.

EVALUATING DISEASE RESISTANCE

Cultivar reaction to the anthracnose fungus must be measured carefully. Large cultivar differences in the amount of defoliation are often noted but observations are rarely consistent from year to year. Much of the variation in cultivar reaction to anthracnose may be explained by understanding the relationship between shoot growth, leaf age, and the period of disease infection. In a recent study (Reid 1995), I found large differences in apparent anthracnose induced defoliation between fruiting shoots and non-fruiting shoots on the same cultivar. Shoots that terminated in a nut cluster had fewer leaves and a greater percentage of leaflets missing than non-fruiting shoots. This observation can be explained by understanding the influence of nut production on shoot growth. On a fruiting shoot, vegetative growth stops when female flowers are produced in early spring. In comparison, non-fruiting shoots continue to grow and produce new leaves into mid-summer. The anthracnose fungus only attacks fully mature leaves during late spring when weather conditions provide the high humidity so important for spore germination (Cline and Neely 1984). During this primary infection period, most leaves on fruiting shoots are susceptible to anthracnose attack, while only the older leaves on non-fruiting (and still actively growing) shoots contract the disease. In simple terms, non-fruiting shoots out-grow the anthracnose fungus. Thus, to the casual observer, a tree producing a large quantity of nuts will look more susceptible to anthracnose than a tree producing few or no nuts.

Differences in apparent susceptibility to anthracnose between fruiting and non-fruiting shoots could explain the wide fluctuations in disease resistance ratings reported for each cultivar. A single cultivar can appear very susceptible or very resistant to anthracnose depending on crop load. In addition, reports that nitrogen fertilization can increase disease resistance (Neely 1979) overlooked the influence nitrogen has on vegetative growth. High rates of nitrogen stimulate non-fruiting shoots to grow late into the summer, producing new leaves that mature well after the anthracnose infection period. These leaves give the tree a healthy appearance and mask the defoliation of older leaves.

To evaluate walnut cultivars for anthracnose resistance, leaves of similar ages must be compared. To provide a meaningful assessment of disease reaction, the response of fruiting shoot leaves to the anthracnose fungus should be noted.

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TOP-WORKING WALNUT FOR TIMBER AND NUTS

David N. Griffith[1]

ABSTRACT.—I describe a project testing the concepts of growing timber-type seedlings into pole-sized trees that can be top-worked with scions from known cultivars to produce both timber and nuts for agroforestry programs.

Agroforestry can be defined as the practice of growing a cultivated crop, a nut crop, and a timber crop all at the same time on the same plot of land. Others at the Fifth Black Walnut Symposium have extensively discussed the cultivated crop, so let me share some thoughts on making the most of combined timber and nut production. Many landowners have established plantations of walnut that were grafted in the nursery to cultivars that regularly produce good crops of high quality nuts. That achieves one of the goals of agroforestry; however, it is often observed that grafts of many cultivars form multiple leaders and are difficult to train to have a straight trunk of sufficient length to make a high grade marketable log. One may shrug off the issue by calling it inherent in that cultivar, diminished apical dominance, or just bad luck.

To avoid the problems associated with nut cultivars, I propose planting seed or seedlings that were bred for strong apical dominance. After these timber-type saplings have reached sufficient height, they can be grafted to a nut-bearing cultivar of your choice above what will become a standard, high quality butt log.

Top-working is usually done in the spring when the period of excess sapflow has passed, temperatures of 80 to 85° F are common, and soil moisture is adequate. My favorite time is in late May and early June. I commonly graft out on the limbs a foot or more from the main bole and avoid cutting where branches are over 2 in. in diameter. This minimizes the danger of causing discolored wood in the developing log. I have done bark grafting, side grafting, chip budding, greenwood budding, and green-tip grafting to topwork black walnut trees. Other techniques will probably work equally well. In most cases, one to four grafts per tree are adequate.

The Extension Services of several states provide booklets on topworking trees. These booklets usually describe the procedure concisely. If you are interested in a deeper study to increase your understanding and to give yourself more options, I recommend *The Grafter's Handbook* by R. J. Garner or *Plant Propagation Principles and Practice* by Hartman, Kester, and Davies.
The successful nurturing of a tree from seed or seedling to a heavy producer of fine nuts above a high quality butt log is often a challenge requiring some hard choices and TLC. The process, however, can be a labor of love with very rewarding results.

The chosen length of the future log is usually reached by a compromise. Logs are usually marketed in lengths of 8, 10, or 12 ft with an extra foot for trimming. Diameter at the small end times the length determines the board foot volume, so longer logs with the same diameter at the small end are worth more. For heavy nut production, the tree must have a large leafy crown which can make the tree top-heavy if the top outgrows the strength of the trunk, i.e., longer trunks are more vulnerable to wind damage.

As the seedling grows into a sapling, there may be a need to do some training or corrective pruning in order to get the desired form. Two rules of thumb for pruning are to never remove more than a third of the leaf area during any one

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year and never prune off the lower branches higher than half the height of the tree. After the tree has been grafted to the nut-producing cultivar, it may be necessary to delay pruning lower limbs until the trunk has gained some more diameter to support the rapidly growing top. But over time, all those limbs can be safely removed, leaving an excellent clear bole below the graft.

My current top-working project consists of grafting the finest timber-type selections I can find across the southern United States to form a seed orchard for the production of genetically improved seed for timber production. Scionwood from these selections is being top-grafted to trees in a planting started as a progeny test 9 years ago. The best of these trees are approximately 30 ft tall with stem diameters around 7 in. Most of the grafting is being done above a 10 to 14 ft log. Although nut production is of minor importance with these timber-type selections, I share the concern of other agroforesters as I prepare to produce seed for the forest nursery industry.

Occasionally I hear reports of grafted trees (northern cultivars) that are thriving and producing well in the South, but sound information is scarce. I am not aware of any southern selections that have been grafted commercially for nut production; however, I am sure we can find good ones if we try. By fully utilizing the technique of topworking timber-type saplings to appropriate nut-producing cultivars, we can reach the goal of agroforestry by growing thousands and thousands of board feet of excellent timber along with tons and tons of excellent nuts!

HAMMONS' SHO-NEFF PLANTATION—COMBINING RESEARCH, TECHNOLOGY TRANSFER, AND AGRIBUSINESS

James E. Jones, H. "Gene" Garrett, and J. W. Van Sambeek[1]

ABSTRACT.—The 790 acre Sho-Neff Plantation in southwest Missouri is internationally recognized for its contributions to the production of eastern black walnut for nuts and timber and application of various agroforestry practices. Cooperative research at Sho-Neff Plantation has significantly advanced the science of agroforestry using eastern black walnut as a model. More than 40 research publications and theses have been the subject of concepts or data collected from this important center of agroforestry, research, technology transfer, and agribusiness.

Sho-Neff Plantation was started in 1974 when Orion Shockley and Elnor Neff Shockley purchased 315 acres of land in southwest Missouri (Cedar County). Their initial purchase included the farmstead, the Island, and upland fields adjacent to the Sac River. Initially they contracted with Hammons Products Company located in Stockton, Missouri to establish plantings of eastern black walnut on the upland sites. In 1977, the Shockley's decided to move to the state of Washington and sold Sho-Neff Plantation to Hammons Products Company. Subsequent land purchases along Cedar Creek have increased the current land base to 790 acres of which more than 384 acres have been planted to eastern black walnut and other trees.

Walnut plantings in 1975 were established on a 20' x 40' (54 trees per acre) spacing. The wide spacing between rows was chosen so that various agronomic crops could be grown between the walnut rows until the walnuts began producing nuts for the nut processing plant in Stockton. Plantings made after 1975 were established on a 10' x 40' spacing (108 trees per acre) as a compromise between maximizing the economic gain from multicropping and securing genetic gain from intense selection for desired characteristics as plantings were thinned.

In the early 1990s, the Sho-Neff Plantation Research Advisory Committee was created to discuss on-going activities and review proposals for new research projects. This committee includes staff from Hammons Products Company, Missouri Department of Conservation, the University of Missouri, and the USDA Forest Service. The primary research goal has remained development of appropriate practices for managing the walnut trees to achieve early, consistent, and prolific production of high quality nuts for the processing plant. Management of the trees has taken priority over the agroforestry practices when conflicts arose.

Since establishment, all trees continue to be maintained in a weed-free zone 4' to 10' wide through annual application of herbicides. Liquid fertilizers are tank-mixed with the herbicides. Operation plantings of soybeans, winter wheat, and milo were used the first 10 years after establishing the walnut or until yields where 30 to 40% below expected because of increasing competition for light and nutrients by the walnut trees. University of Missouri researchers have shown that yield and digestibility of grass forages, especially tall fescue, can be significantly

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increased when grown under walnut trees. Although tall fescue was initially proposed, alleys were not seeded to tall fescue because recent research results have shown tall fescue may be too competitive for soil moisture and nitrogen. A mixture of orchard grass and red clover was selected and has been planted between the tree rows for hay production.

Sho-Neff Plantation was divided into over 25 large areas based on topography, soil type, and research activity. The 16-acre provenance-progeny test established in 1976 on a wide floodplain formed by the Sac River (Area 12) was a cooperative study between the Hammons Products Company and the Missouri Department of Conservation to test various timber- and nut-type selections for superior growth and nut production. The University of Missouri and the USDA Forest Service are also conducting cooperative studies on genetic improvement and wood quality from this walnut planting. No adverse effects have been found in wood properties of open-grown, alleycropped walnuts. Currently, nuts produced in this progeny are being sold as level 1 certified seed after removal of the poorest performing walnut trees.

The primary objective of the black walnut tree improvement program continues to be selection of trees with excellent nut bearing characteristics on stems managed for veneer production. The study began by monitoring nut production on a few trees in 1983 and grew to over 13,000 trees by 1993. The impacts of curculio weevils on nut production have been evaluated on two acceptable upland sites (Area 16; SI 65 and Area 23; SI 55 to 60) and an excellent bottomland site (Area 2; SI 80) since 1987. On another one of these upland areas (Area 17; SI 65), a microjet irrigation system was installed in cooperation with the USDA Forest Service to test the effects of maintaining high soil moisture levels and fertilization on nut production and quality. Weather towers are maintained in cooperation with the University of Missouri on the same upland area (Area 23) and a bottomland area (Area 12; SI 90) to monitor potential impacts of rainfall, temperature, wind speed and direction, and relative humidity on flower development, pollen dispersal, pollination, and nut development.

Several studies have been established to examine the long-term effects of fertilization on tree growth and nut production. Recently studies were initiated to evaluate effects of smooth bromegrass and alfalfa on walnut growth and nut production (Area 24 and 25; SI 60 to 65). In addition, studies are currently being established to evaluate effects of summer grazing of cattle on tree growth, quality, and nut production.

Sho-Neff Plantation and staff host between 500 and 700 visitors annually for meetings at the conference center and field tours of various agroforestry demonstration projects. The Shockley home was converted to a conference center in the early 1980's and now houses a reference library and various exhibits on tree care, insect problems, wood quality, and nut production. For the last 14 years, Sho-Neff Plantation in cooperation with the University of Missouri, Missouri Department of Conservation, and the USDA Forest Service has sponsored an all-day Spring and a Fall Field Day with indoor technical presentations and field tours. Sho-Neff Plantation also has been the site of field tours for several national meetings including the Walnut Council (1975, 1985, and 1996) and the North America Agroforestry Conference (1991). In addition, it has hosted many smaller groups including agribusiness classes from Southwest Missouri State University, Missouri Farm Bureau, Farm Home Administration, and various lending institutions.

Observations and findings from the Sho-Neff Plantation have been the basis of numerous news stories, articles, theses, and research publications. The following chronological list of publications reflects the important contributions the Hammon's Sho-Neff Plantation has made to agroforestry, research, technology transfer, and agribusiness.

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THE SILVICULTURE-WOOD QUALITY CONNECTION IN EASTERN BLACK WALNUT

Bruce E. Cutter, John E. Phelps, and Douglas D. Stokke[1]

ABSTRACT.—The known effects of silvicultural practices on eastern black walnut (*Juglans nigra* L.) wood quality are reviewed. Since desirable quality differs from end user to end user, no specific recommendations are made.

INTRODUCTION

In this paper we review the body of knowledge relating wood quality in eastern black walnut (*Juglans nigra* L.) to stand management activities. The latter can be broadly defined as whatever the landowner undertakes that influences the growth of the trees and/or the stand. This includes no action as well since, as we will see, failure to control weeds, remove diseased trees, or to thin also will influence the growth of the stand. A quick review of the literature indicates that black walnut quality-site knowledge is lacking in many areas. While there have been many examples of guidebooks discussing walnut stand management—USDA General Technical Report NC-38 by Schlesinger and Funk (1977) as an example—none of these discuss wood quality. In the Fourth Black Walnut Symposium, Phelps (1989) addressed the tree growth-wood quality relationship from the wood properties perspective.

Wood quality is measured by several parameters whose importance vary from end-user to end-user. These parameters might include cell length, density or specific gravity, growth rate, earlywood-latewood ratio, or, particularly in the case of black walnut, heartwood color. While there will be some exceptions, strength is usually not a concern in black walnut utilization since the majority of the wood is used for decorative veneers and furniture. The notable exception is in the gunstock market where a certain minimum strength may be required for safety in the trigger grip area.

In most wood technology or wood utilization texts, three general sources of variation in wood (and wood properties) are listed: genetics, tree (cambial) age, and environment. The latter includes all the factors typically assumed to be environmental such as climate, soil fertility, moisture, photoperiod, etc. What many people overlook is that deliberate (or accidental!) management activities undertaken by the landowner constitute an environmental impact as well. Typical or traditional forest management activities might include thinning, pruning, fertilization, irrigation, etc. Less activities might include mechanical agitation by shakers to hurry nut drop as is common in harvesting English walnuts or pecans (Reid 1993). Another atypical management activity might be agroforestry alleycropping where alleyways are used for rowcrops and grazing lanes (Garrett *et al.* 1991).

While the bulk of this paper is devoted to management activities, we will first spend a few minutes briefly reviewing the other two sources of wood quality variation—genetics and tree age.

GENETICS AND TREE AGE

Proper selection of planting stock for the desired end purpose may be considered a management activity. There has been considerable time and

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effort expended over the years in black walnut tree improvement programs with modest results (Beineke 1985; Bey 1973; Chenowerth 1995; Rink 1987; Rink and Phelps 1989; Rink *et al.* 1994a, 1994b). Most of the work has been aimed at improving growth and form or at increasing nut yield (Garrett *et al.* 1994, Jones *et al.* 1995). Rink *et al.* (1994a) evaluated wood quality in a thinning of plantation-grown walnut and found that selection for timber growth showed modest genetic advantage. Rink (1987) also has found low heritability for heartwood color in black walnut suggesting that environmental/management factors play a significant role in determining this important wood quality parameter.

Chen *et al.* (1995) examined knots, pin knots, and pin knot clusters in walnut boards cut from logs obtained from a precommercial thinning of a walnut-agroforestry plantation. They found no advantage over selection for either nut or timber characteristics with respect to knots, pin knots, or pin knot clusters. They suggested that retention of suppressed buds was controlled by environmental factors, not genetics.

There were early efforts to produce figured walnut by grafting (Lamb 1940). Walters (1951) reported that grafted trees had more figure in the outer section of the stem then the inner section.

In most tree species, the early years of growth produce wood that is variously termed "immature wood" or "juvenile wood" (Panshin and de Zeeuw 1980, Haygreen and Bowyer 1989). This wood also has been referred to as "crown-formed wood" since it is associated with the live crown section of the tree stem. Typically, this wood is characterized by shorter cells, steeper S_2 cell wall microfibril angles, and altered chemical composition. As a result of these changes, some physical and mechanical properties are altered as well—increased longitudinal shrinkage, decreased density, decreased strength. Walnut does not appear to be an exception. Cutter and Garrett (1993) found that fiber length increased from pith to bark in a study of 15-year-old thinnings from an agroforestry plantation, i.e., immature wood was composed of shorter cells. Juvenile wood characterization in walnut has been limited to date.

MANAGEMENT ACTIVITIES

FERTILIZATION AND IRRIGATION

Explicit references to the influence of either walnut fertilization or irrigation vis-a-vis walnut wood quality in the literature are lacking. Insofar as improving the growth and vigor of the trees, it is difficult to say that either of these practices would be detrimental to tree and/or wood quality. Certainly, based on the results from other species, one could infer that the results would be at best favorable (Murphey *et al.* 1973a, 1973b; Scowcroft and Stein 1986). Black walnut fertilization research has focused on the effect of fertilization on nut yield (Jones *et al.* 1995).

GRAZING

In many areas of the United States, forest grazing of cattle is a common practice (Lundgren *et al.* 1983). Some agencies explicitly recommend against grazing (Hershey 1991, Williams 1933). Much of the evidence cited against grazing appears to be either anecdotal or based on uncontrolled grazing of not only cattle, but hogs, sheep, goats, etc. and is related to soil erosion and watershed degradation (Patric and Helvey 1986). Cutter *et al.* (1996) found that controlled grazing had no influence on tree grade in slash pine.

PRUNING

Pruning is done for several reasons including the production of a clear stem, corrective pruning to improve tree form, and (in alleycropping regimes) removal of low branches that might impede the access of agricultural equipment. While there have been numerous studies showing the proper way to prune to minimize bole damage, it is important to remember that this is a deliberate wounding of the tree, regardless of the desirability of the end result. While pruning is frequently done to correct a misshapen stem, Reeves (1984) found that the tree will try to correct this on its own, and, if left alone, will do a very good job.

The time of year that pruning occurs has been shown to play a role in both wound healing and scarring. Armstrong *et al.* (1981) and Smith (1980) found that fall pruning/wounding produced more scarring and discoloration in walnuts than did late winter/early spring pruning.

Studies by Clark and several of his co-workers indicated that pruning, while stimulating growth, sometimes produced undesirable results including epicormic branching (Clark 1955, 1961; Clark and Seidel 1961). Indeed, even 25 years following pruning, the pruning wounds had not healed on some stems in one study (Shigo *et al.* 1978, 1979). Shigo and his co-workers noted that dark bands of discolored heartwood were associated with pruning wounds. If the production of clear, uniform color wood is the desired result, this is clearly undesirable.

The general recommendation that may be made is that pruning should be done at an early age and limited to small diameter branches (say less than 1 in. in diameter). Early pruning will allow the production of the maximum amount of clear wood.

THINNING

Typically, thinning is thought of as removal of poorly formed trees, low vigor trees, diseased trees, etc. From a traditional forest management standpoint, thinning is either pre-commercial (i.e., the cut trees are left on the ground) or commercial (the removed trees are large enough for product recovery). In either event, the result is increased water and nutrient availability for the residual stand. In some instances, there have been reports of increased levels of limb-related defects associated with heavily thinned hardwood stands (Sonderman 1986).

Paul (1943) reported that open-grown black walnut had higher density than did forest-grown walnut. Open-grown was defined at that time as "trees growing singly or in small scattered groups in pastures and relatively open farm woodlots." This might be analogous to stand densities seen in many agroforestry configurations. In a latter paper, Paul (1963) recommended that management practices producing conditions similar to those where open grown walnut occurs be followed.

On the other hand, Landt and Phares (1973) suggested that open grown walnut would tend to be forked and limby while forest grown walnut would have a straight, clear stem. According to them, the forest grown stems would have a dark colored heartwood with a narrow sapwood band while open grown trees would have lighter heartwood and wider sapwood rings.

Phelps and Workman (1992) compared vessel element area in naturally-grown walnut against plantation grown walnut trees. They found that the faster-growing plantation trees had wider growth rings which in turn have wider latewood zones. This results in a reduction in vessel area in the cross-section that causes poorer wood texture. On the other hand, stand management favors more uniform wood texture.

Other literature suggests that trees growing in a crowded stand may have greater height to diameter ratios. In a study of the effect of stand density, Holbrook and Putz (1989) found that sweetgum (*Liquidambar styraciflua* L.), which like walnut is a light-demanding tree, apparently allocated more wood to height growth than to diameter.

WEED CONTROL

Weed control also could be termed "competing vegetation control" since, under some scenarios, the competing vegetation may be rowcrops or other tree species. Numerous papers have shown that vegetation control during establishment phases of walnut stands is necessary for optimum growth response (Schlesinger and Van Sambeek 1986, Van Sambeek *et al.* 1989). What many do not realize is that the competition for available nutrients and water continues once the tree is into the sapling or pole stage. If the competing vegetation is other trees, be they walnut or some other species, then vegetation control is termed thinning. If the competing vegetation is an annual (such as corn or soybeans) or a perennial (such as clover or lespedeza), then the tree line may need to be kept vegetation-free in order for the tree to successfully compete for water and nutrients. This can be done either through chemical or mechanical means (Jones *et al.* 1990). Cutter and Garrett (1993) indicated that declining growth in an agroforestry plantation on an exceptional site (SI=90+) was coincident with conversion of the alleyways to a perennial cover crop.

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INFLUENCE OF GEOGRAPHIC ORIGIN AND SOIL PROPERTIES ON COLOR OF BLACK WALNUT VENEER

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Walnut veneer from sites in Missouri, Illinois, and Indiana was analyzed for color attributes and chemical properties. Veneer color also was compared to an industry color standard. Soil chemical and physical properties were measured on selected sites in each state. In general, walnut trees grown on soils with equal proportions of sand, silt, and clay have better veneer color attributes than trees grown on soils with high clay/sand or clay/silt ratios.

Walnut veneer color is an important quality attribute and determinant of value. In the past, the study of walnut color has been done on either walnut lumber or on veneer not graded by the veneer industry. Past studies have shown that the color of veneer had a low heritability suggesting a greater environmental influence than genetic influence during formation of heartwood. The designations used for color science are set by the Commission Internationale de l'Eclairage (CIE) and include L* for lightness, a* for red-green color range, and b* for yellow-blue color range.

Color analysis was done on 239 sheets of veneer from 128 veneer quality trees in three states and six sites for our study. The color analysis showed there was no difference in lightness (L*) between states or sites within states. In the red-green color range (a*), there was a difference between the three states but not the sites within states. The veneer from Missouri was redder than the veneer from Illinois or Indiana. There was no difference in a* between Illinois and Indiana. There is, however, a difference in the yellow-blue color range (b*) between sites within states but not between states. One site in Indiana was more yellow than the other five sites.

All the veneer from each site and state was compared to a mouse gray industry standard (i.e., a walnut veneer sample which represents an "ideal" color for the walnut market) in the red-green and yellow-blue ranges. The veneer from Missouri tended to be more red and blue than the veneer standard. The veneer from Illinois and Indiana tended to be more green and blue than the standard.

From 3 to 10 trees per site (total of 30 trees) that had been harvested were chosen for wood and soil chemical analysis. The finished veneer was analyzed for nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), aluminum (Al), iron (Fe), sodium (Na), manganese (Mn), zinc (Zn), copper (Cu), boron (B), lead (Pb), nickel (Ni), chromium (Cr), and cadmium (Cd). The soil within 4 ft of each tree was analyzed for pH, N, P, K, Ca, Mg, Na, Mn, Fe, Zn, Cu, Pb, Ni, Cd, Cr, % sand, % clay, and % silt. The color variables were analyzed for their relationship with the wood and soil elements. Increasing L* values were correlated with increasing Al, decreasing N, and decreasing Mg levels in the wood and increasing Cd levels in the soil. Increasing a* values were not correlated with soil elements but were correlated with increasing Al, Ca, and Cu and decreasing Zn levels in the veneer. Increasing b* values also were not correlated with any soil elements but were correlated with decreasing K levels in the veneer.

Veneer L* (lightness) was also directly correlated with clay/sand, clay/silt, and clay levels in the soil. The red-green veneer color attribute (a*) was inversely correlated with soil texture index, defined as 270.1*((%sand/100) x (%silt/100) x (%clay/100)). No significant correlation was found between b* and soil physical properties.

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Poster presentation at the Fifth Black Walnut Symposium.

One interpretation of these correlations with soil physical characteristics is that veneer color attributes are generally poorer on sites that have high clay/sand or clay/silt ratios. Conversely, walnut veneer color should improve on soils that have more nearly equal proportions of sand, silt, and clay.

Additional study sites within and along the margins of the natural walnut range, especially sites in states other than Illinois, Indiana, Missouri, and Iowa (a state in which we have done some additional sampling and analysis), are needed to test the strength of the correlations and possible management implications. Details on materials and methods, results, and discussion for the study done in Illinois, Indiana, and Missouri are contained in Workman (1996).

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PROCESSING SMALL QUANTITIES OF WALNUT LOGS FOR LUMBER AND CRAFT ITEMS

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ABSTRACT.—Many walnut plantation owners and woodworking hobbyists would like to process small quantities of walnut logs into lumber and discs for furniture and craft items. Various options exist for sawing, drying, and processing small diameter or short logs into lumber and cross-sectional discs. Portable band saws are a safe and inexpensive log breakdown option to commercial headsaw mills. Processing using the saw-dry-rip method will yield higher quantities of usable lumber from small diameter logs than the conventional saw-rip-dry method. Small quantities of lumber and discs can be inexpensively air dried under shelters or open sheds followed by approximately 15 to 30 days indoor storage at room temperatures. Several designs exist for constructing solar kilns for small quantities of lumber. Pretreatment of craft items with PEG 1000 is an acceptable procedure to reduce checking during drying of lumber for craft items.

Few commercial markets are available to the landowner for small diameter (4 to 8 in.) logs following a thinning operation within black walnut plantations or natural stands. Options have included selling logs to hobbyists, chipping the material for mulch or bedding, cutting logs into firewood, producing fence posts, or marketing logs as pulpwood. As firewood, black walnut is an acceptable wood to burn and is better than most low-density hardwoods and softwoods. Walnut chips should be used with caution as mulch around many plants and as bedding for animals. Walnut chips can cause horses to go lame or even die. Walnut has been shown to sensitize a few people who handle it; fortunately incidence of eye irritation or skin dermatitis from harvesting or processing walnut are considered rare. Sawyers and wood workers can limit their exposure by harvesting in the fall or winter and processing wood in cool environments to reduce perspiration.

The availability of portable sawmills and chainsaw mills have made it easier to find operators who will cut small diameter walnut logs into lumber. Although lowest in cost, chainsaw mills have the major disadvantage of a large kerf. Portable bandsaws offer several advantages over headsaw rigs to operators who have small quantities of logs to be cut into lumber. First, blades for bandsaws are relatively inexpensive and easily replaced if damaged by metal in a log compared to replacing the carbide tips of circular blades on larger stationary headrigs. Secondly, the smaller size of a portable bandsaw headrig is better adapted for handling small diameter logs. Third, the smaller kerf cut by thin-flexible bands means a higher yield of lumber from small diameter logs.

Usually small diameter walnut logs are best cut using grade sawing which is sawing around the log rather than live sawing which has all sawlines in the same plane. Grade sawing generally produces lumber with better grades and higher yields because defects associated with

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pruned branches and a wavy pith can be contained within a center cant. Green lumber should be cut at least 10% larger than final planed width and thickness to allow for shrinkage during drying.

Several studies have shown that the saw, dry, and rip (SDR) process developed by the Forest Products Laboratory is capable of producing higher yields of lumber with fewer defects than the conventional process of saw, rip, and dry (SRD). The SDR process essentially cuts the log into slabs that are dried before edging the slabs to standard rough cut lumber widths. Under the SDR process, stresses created in a steam-heated dry kiln using the standard T6D4 schedule for 1 in. thick walnut lumber are reduced in the wider, non-edged boards. Kiln-drying caused some crook warpage to develop both in the SRD boards and SDR flitches; however, much of the crook warpage could be removed during ripping the SDR flitches. No differences were found for twist, bow, or cup warpage between SDR and SRD lumber from 6 to 9 in. diameter walnut logs. Thickness shrinkage was greater for SDR lumber than for conventional SRD lumber because the bark-covered edges may have forced more drying from the two cut faces on the SDR lumber.

The moisture content of freshly cut walnut heartwood is typically 90% or almost one pound of water for each pound of oven-dried wood. If used in the green condition, the lumber will shrink, crack, and warp as it dries to the low moisture contents (6 to 10%) required for most woodworking projects. To air dry green walnut lumber, it must be stacked with uniform 5/8 to 1 in. square stickers placed approximately 1 to 2 ft apart between each layer to facilitate air flow across the surface of the lumber. Stickers should be placed within 1 in. of the end of the boards and carefully aligned vertically to reduce warpage of lumber in the lower layers. The top of the stack is weighted to keep the boards flat and reduce warpage. In addition, the ends of the boards are frequently coated with paraffin to reduce end checking.

In the 1980's a study was conducted to compare drying lumber in a heated room, a heated room with a fan, an unheated shed, outdoors under a roof, an unheated attic with fan, and inside a freezer. It took 40 to 80 days to air dry 1 in. thick lumber to a 20% moisture content under all conditions, except inside a freezer which required over 5 months. It took between 60 and 100 days to air dry a stack of 2 in. thick lumber under all conditions, except inside the freezer which required more than 6 months. To dry the lumber to a 10% moisture content, lumber was then moved to a heated room for 2 weeks. The volumetric shrinkage, amount of warpage (twist, bow, crook, and cup), and amount of end and surface check was similar for all six methods of air-drying. Final recommendations included drying small quantities of hardwood lumber in warm air either by outside exposure during the warm months of the year or indoors in heated space during cooler months. An attic with good air flow permitted equally rapid drying if the attic temperature was equivalent to summer air temperatures or indoor air temperatures during the heating season. The use of a fan to circulate air through the stack produced little additional benefit.

During the energy crisis of the 1970's, researchers designed and tested several solar kilns as an energy-efficient and economically attractive method to dry lumber for small sawmill managers, wood shop operators, and wood hobbyists. Several of these designs were patented and a few are commercially available. An inexpensive, efficient solar collector can be built using aluminum beverage cans, aluminum foil, plywood, insulation, and fiberglass panels for approximately $\$6.50/ft^2$ of collector surface. Fans are used to move air through the solar collector and into the kiln where the lumber is stacked. From March through November, a 128 ft^2 solar collector connected to an insulated kiln can collect slightly less than 150,000 BTU/day in southern Illinois. This was sufficient to dry 500 board feet of green walnut lumber (90% moisture content) down to 10% moisture content in approximately 3 to 4 weeks.

One option to prevent shrinkage as wood dries is to add chemicals such as polyethylene glycol (PEG) as a bulking agent. The cell walls and lumens of wood from freshly cut lumber are filled with water. Above the fiber saturation point (approximately 25 to 40%), water moves from the cell lumens to the outside of the board resulting in very little shrinkage. Below the fiber saturation point, bound water in the cell walls diffuses out causing the wood fibers to shrink. Radial (across the growth rings), tangential (along the growth rings), and volumetric shrinkage for walnut heartwood averages 5.5, 7.8, and 12.8%

from green to ovendry moisture content. Bulking agents replace the bound water in the cells walls of the wood fibers so they do not shrink.

Most hobbyists have learned that PEG 1000 is an excellent non-toxic bulking agent. It is a waxlike chemical resembling paraffin that is a solid at room temperature, but readily dissolves in warm water. The major disadvantage to using PEG 1000 has been the expense, the time required for it to penetrate 1 in. and 2 in. thick wood disks, and difficulties encountered when gluing or finishing PEG-treated lumber. After soaking for 2 weeks in a 50% solution of PEG 1000, 1 in. thick disks cut from small diameter walnut logs decreased in diameter by 1 to 2% when rapidly dried in a 140°F forced-air oven. Other authors have reported that relatively light treatments of PEG 1000 into the outer shell of green wood bowls, turnings, art carvings, gun stocks, and other craft items will prevent drying degrade.

Large sawmills match the light-colored sapwood to the dark-colored heartwood of walnut by steaming the logs. Steaming is relatively expensive unless large quantities of walnut logs will be processed. Unfortunately, small diameter walnut logs are mostly sapwood. An option that still needs testing for darkening the sapwood is to mark and girdle trees to be cut approximately 1 year before they are harvested. This will induce formation of pathological heartwood as the trees slowly die. Because the physical and chemical properties of pathological heartwood are similar to normal heartwood, these logs can be processed like newly cut logs from live trees.

The USDA Forest Service San Dimas Technical Development Center conducted an extensive search and recently published the *Smallwood Equipment Catalog* of equipment used to harvest and process trees from 5 to 20 ft stem diameters. This catalog provides ideas for other innovative ways to process small diameter logs, some of which can be easily applied to small diameter black walnut logs with a little experimenting. For the hobbyist, inventiveness and adaptation of technology can get the job done with satisfying results.

UTILIZATION OF LUMBER FROM SMALL-DIAMETER BLACK WALNUT LOGS

Robert E. Bodkin, Peter Y. S. Chen, Douglas D. Stokke, and J. W. Van Sambeek[1]

ABSTRACT.—Many walnut plantings have been established in the last 10 to 30 years that are now in need of thinning. Unfortunately, the only significant market that exists for most landowners for the small-diameter trees is firewood. We examined the feasibility of processing these rapidly grown, small-diameter (6 to 10 in.) logs into lumber to produce high-value panels and craft items. This abstract describes several processing methods that can be used to produce higher-valued products.

Several companies market portable bandsaws capable of safely cutting small-diameter logs into 4/4 or 8/4 lumber. Walnut lumber from plantation thinnings can be air dried, but it will require more stickers and weight across the top of the stack to control twisting and warping due to the higher proportions of juvenile wood. When dry, the lumber can be finished along one edge with a jointer before cutting on a table saw to square the lumber. Lumber also can be run across a 6- or 8-inch-wide jointer or through a 12-inch-wide planer to reveal grain pattern and defects. A small industrial planer is needed to produce lumber of uniform thickness.

Lumber from small-diameter logs will potentially show numerous kinds and sizes of knots. Lumber can be crosscut to remove areas with large or loose knots, and may be further cut on a table saw to remove sapwood. Boards of the same width and thickness can be used to create longer clear lumber by end matching and gluing them together using finger joints. Finger joint cutters are available for either small shapers or for some of the larger routers when mounted to a table with a fence. Alternatively, short boards of similar length and thickness can be formed into wide panels. Boards should be color matched, edge planed, and glued using steel bar clamps. Other alternatives include use in craft-type applications such as chessboards, onion ring bowls, and trivets. These can be made from edge-glued panels. In addition, decorative shelving from clear, finger-jointed lumber also may be manufactured from small-diameter walnut stems.

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GUIDE TO UNDERSTANDING HOW VENEER IS GRADED

Larry R. Frye[1]

ABSTRACT.—A voluntary standard for manufacture of decorative faced veneers for domestic and export sale has been developed by the industry. These standards cover sampling procedures, moisture content, and veneer thickness. Black walnut veneer is usually cut at 1/45 in. for domestic markets and 1/50 in. for the export market. Veneer is sold primarily on eye appeal determined by color, structure, figure, and estimated yield. Veneer can fall into one of five grades based on length, eye appeal, and yield decreasing defects.

This paper is intended to serve as a brief reference guide on the subject of the basic system used to grade decorative face veneer. Unlike lumber which is sold on the basis of an established set of grading rules, veneer is sold on eye-appeal. The requirement of individual customers will vary. Although an industry standard does not exist, a task force of members of the American Furniture Manufacturers Association (AFMA), the Hardwood Plywood and Veneer Association (HPVA), and the Fine Hardwood Veneer Association (FHVA) agreed in 1988 to a voluntary standard for the manufacture of decorative faced veneers (Industry Standard DFV-1 1988). In 1995, the standard was revised (Industry Standard DFV-1 1995); however, this time the AFMA optioned not to sign the agreement. The voluntary standard covers sampling procedures, moisture content, and veneer thickness. A copy of the DFV-1 1995 is available for purchase from the Hardwood Plywood & Veneer Association, P.O. Box 2789, Reston, Virginia 22090.

When veneer is sliced for the domestic market, two to five samples (depending on the size and species of the log) are pulled at the exit end of the veneer drier and later shown to the veneer purchaser. Veneer sliced for the export market is dried, clipped, and bundled. Each bundle of flat sliced veneer will contain 24 sheets. Each bundle of quartered and rift-cut veneer will contain 32 sheets of veneer. The moisture content standard for domestic veneer is 7 to 11%. The moisture content for most export veneer is 12 to 18%.

The thickness of the veneer will vary for the species and whether or not the veneer is for domestic or export use (Table 1). In the final analysis, the buyer has some say in the thickness. For most species, the thickness of domestic veneer is 1/38 in. (0.026 in. or 0.65 mm) with a 0.000 to +0.003 in. tolerance. The thickness of most veneer for the international market is 1/45 in. (0.022 in. or 0.55 mm) with a +/- 0.002 in. tolerance. There are optional special custom sliced thicknesses for most species for Japan of 1/64 in. (0.015 in. or 0.40 mm), 1/72 in. (0.014 in. or 0.35 mm), 1/85 in. (0.013 in. or 0.30 mm) and 1/125 in. (0.008 in. or 0.20 mm) with +/- 0.002 in. tolerances.

CRITERIA CONSIDERATIONS FOR GRADING VENEER

The overall look of the veneer is an important initial consideration. Color will be an important grading criterion. Structure as determined by the rate of growth, size of the heart, and

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Table 1.—Voluntary U.S. domestic and international veneer thickness

Species	Domestic U.S. veneer				International veneer			
	Thickness		Tolerance		Thickness		Tolerance	
	In.	*mm*	*In.*	*In.*	*In.*	*mm*	*In.*	*In.*
Most species	1/38	0.65	0.026	0.026-0.029	1/45	0.55	0.022	0.020-0.024
Black walnut	1/45	0.55	0.022	0.022-0.025	1/50	0.50	0.020	0.018-0.022
Black cherry	1/42	0.60	0.024	0.024-0.027	1/50	0.50	0.020	0.018-0.022
Red oak	1/38	0.65	0.026	0.026-0.029	1/45	0.55	0.022	0.020-0.024
Rift cut red oak	1/45	0.55	0.022	0.022-0.025	1/45	0.55	0.022	0.020-0.024
Rift cut white oak	1/45	0.55	0.022	0.022-0.025	1/45	0.55	0.022	0.020-0.024
Pine, southern yellow	1/38	0.65	0.026	0.026-0.029	1/42	0.60	0.024	0.022-0.026
Pine, white	1/27	0.95	0.037	0.037-0.040	1/42	0.60	0.024	0.022-0.026
Pine, white (knotty)	1/27	0.95	0.037	0.037-0.040	1/27	0.95	0.037	0.035-0.039

straightness of the grain will also be considered along with the overall yield reductions due to knots, holes, etc.

Because domestic and export veneers are cut at different thicknesses, they have separate showrooms or sales areas. Veneers of different species are not mixed. The length of the veneer cuts will be a factor in determining grade and use.

Length is an important consideration in the final grade. The length of the log largely determines the initial length of the veneer after it is cropped to remove end-check and other defects. The length of the veneer without major defects will determine its utilization opportunities while the length of the final cuts will determine the marketing opportunities.

Color, structure, and the figure determine the eye appeal of decorative face veneers. Color is the most important consideration for most customers. The veneer must be pleasing to the buyers and be able to be finished to offer the look specified by the designer. Color is a function of the growing conditions of the tree and can be a reflection of the quality of the manufacturing. When buyers purchase whole truck loads of a given species, they will be looking for the veneer to have the same basic color.

Structure is another very important consideration for most customers. They are looking for veneer from trees that have had a fairly even rate of growth. Variations between fast and slow growth create less acceptable veneer. Fast grown trees are less common and veneer from them does not mix well with normally grown trees with approximately eight growth rings per inch. The pattern of the growth rings also determines the size of the heart. A narrow heart look comes from slow grown trees and is preferred. The wider heart veneers come from faster grown trees. Sweep in a log and an off-centered heart will cause a variable look that is not desired. Figured wood is desired by some customers; however, it is not desired by most buyers and designers.

The buyers determine the estimated yield of usable veneer each flitch contains. Yields are determined by color and structure along with any reductions for pin-knots, flares, holes, sound knots, bird peck, shake, mineral stain, and any other grade influencing factors.

BASIC VENEER GRADES

STOCK PANEL GRADE can be any veneer with lengths of 100 in. and longer. It is used to produce 4 x 8 ft plywood sheets that are not V-grooved. These panels normally fall into either Architectural, A, AB, or B-Sound (from best to worst) grades.

V-GROOVED WALL PANEL GRADE can also be veneer with lengths of 100 in. or longer. They are used to produce panels similar to stock panel grade. V-grooved wall panels will usually accept

grade. V-grooved wall panels will usually accept color, structure, and yield factors not allowed in stock panel grade.

DESK AND DOOR GRADE can be veneer with lengths of 60 in. to 98 in. A 60 in. cut after clipping must be possible to fit into this category. These panels can fall into either Architectural, A, or B grades.

FURNITURE GRADE can be veneer with cuts of 18 to 30 in. Many of the furniture cuts are 18 to 24 in.; however, cuts after clipping must yield 30 in. to qualify as a side panel for furniture. The furniture grades are A, A-B, and C.

ARCHITECTURAL GRADE can include veneer with assorted lengths that has an uniform desirable color with straight parallel grain and free of yield decreasing defects. Lengths will vary to fit into the design requirements. Veneer for this grade generally ranges from 90 to 220 in. The usual grades are A and B.

CONCLUSIONS

It takes several years of study and apprentice time to fully comprehend the process used to grade decorative face veneer. It is helpful for tree farmers to at least have an explanation of the process to appreciate the need for quality considerations at the tree growing phase. Tall, straight, evenly-grown trees free of pin-knots, bird peck, metal, and mineral are going to bring the greatest opportunity for maximum economic return. Black walnut trees grown in an environment free from wildfires and livestock grazing will still be the best quality veneer trees.

RISK ANALYSIS OF BLACK WALNUT AND RED OAK PLANTATIONS

Stephen H. Kolison, Jr., Jianbang Gan, and Douglas D. Stokke[1]

ABSTRACT.—Risks and uncertainties are prevalent in timber production due to the nature and length of the production process. This paper examines the volatility of timber prices and the effects of some economic uncertainties and risks such as fluctuations in timber prices and the interest rate on the economic returns of black walnut and red oak plantations. Historical patterns of timber prices for black walnut and oaks are investigated and compared with those of other timber species and stock price. The sensitivity of economic returns from black walnut and red oak plantations to changes in timber prices and the discount rate also is analyzed. Results indicate that the stumpage, sawlog, and veneer log prices for oaks are less volatile than softwood timber prices, but the veneer log price for black walnut is more volatile than that for Douglas-fir. Unit root tests also imply that timber prices for black walnut and oaks have time trends while softwood timber prices do not. Moreover, black walnut plantations have higher economic returns than red oaks even though the timber price for black walnut is more volatile than that for red oaks.

Forest production is a long-term process in which some uncertainties and risks are almost inevitable. In general, these uncertainties and risks include physical and economic uncertainties and risks. Physical uncertainties and risks include disease and pest infestations, fire, severe weather, and other natural disasters. Fluctuations in prices (both input and output prices) and the interest rate represent economic uncertainties and risks. These uncertainties and risks intensify the difficulty in the decision making in forest production.

Black walnut and red oak are among the most valuable hardwood timber species. Many economic analyses of the economic returns associated with black walnut and red oak plantations have been conducted (Thompson 1976, Kincaid *et al.* 1982, Garrett *et al.* 1986, Noweg and Kurtz 1987, Clark and Hutchinson 1989, Kurtz *et al.* 1991). However, there are relatively few studies on uncertainties and risks in black walnut and red oak plantations (Gan *et al.* 1995). This paper assesses the effects of changes in the stumpage price and the discount rate on the economic returns of black walnut and red oak plantations. This study should help black walnut and red oak timber producers better understand the potential financial returns associated with plantations given different types and levels of uncertainty and risk.

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SOME MEASUREMENTS OF RISKS

VARIANCE OF PRESENT NET VALUE

Variance is a widely used indicator of variation of a random variable. In this study, it is applied to measuring the variation of the economic returns from timber production. The economic returns from forest plantations are often calculated using Present Net Value (PNV) as follows:

$$(1) \qquad PNV_T = \sum_{t=0}^{T} \frac{P_t Q_t - C_t}{(1+r)^t}$$

where:
P_t is the timber price at time t;
Q_t is the amount of timber harvested at time t;
C_t is the production cost incurred at time t;
r is the real discount rate;
T is the rotation length.

The economic returns from timber plantations come many years after planting and are unknown at the time of planting. However, we assume that tree growers decide whether or not to grow timber based on the expected value (rational expectation) of the Present Net Value:

$$(2) \qquad E_t(PNV_T) = E(PNV_T | I_t)$$

where:
E_t is the expectation at time t (initial time of the rotation);
PNV_T is the Present Net Value of all the costs and revenues occurred from t to t+T;
I_t is the information available at time t.

Because the major revenue from timber plantations generally comes from the final harvest, tree growers are more concerned with the price of timber at the end of the rotation. We assume that the prices of the input factors for timber production are deterministic and that timber producers know their discount rate, which at this moment also is assumed not to change over the rotation period. Actually, the costs for growing trees normally occur in the early years of the rotation and are easier to predict. Thus, variance of the revenue from the final harvest ($P_T Q_T$), denoted by $Var(P_T Q_T)$, is the major component of $Var(PNV_T)$. Moreover, an individual timber producer generally has no influence over the timber price in competitive markets for black walnut and oak timber. This implies that P_T and Q_T are independent. Therefore, $Var(PNV_T)$ is primarily due to $Var(P_T)$ and $Var(Q_T)$. $Var(P_T)$ represents the variation in timber price, and $Var(Q_T)$ measures the variation in timber yield due to physical uncertainties and risks.

PREDICTABILITY OF TIMBER PRICES

Whether a timber price is predictable is important in decision making regarding tree plantations. If a timber price is predictable, a statistical relation between the price and time can be estimated. However, if the timber price is unpredictable, the uncertainties in the revenue from the timber production will be intensified. Therefore, predictability of a timber price can be used as another indicator for measuring the risk of the timber market. A timber market with predictable prices is less risky than one with unpredictable prices.

Dickey and Fuller (1979, 1981) developed likelihood ratio statistics for autoregressive time series with a unit root. For the model

$$(3) \qquad Y_t = \alpha + \beta t + \rho Y_{t-1} + e_t$$

where $\{e_t\}$ is a sequence of normal independent random variables with zero mean and constant and finite variance. If the null hypothesis H_o: $(\alpha, \beta, \rho) = (0, 0, 1)$ is accepted, then Y_t follows a random walk without a drift. If the null hypothesis H_o: $(\alpha, \beta, \rho) = (\alpha, 0, 1)$ is accepted, then Y_t follows a random walk with a drift (equal to α). Otherwise, Y_t is predictable, i.e., Y_t has a time trend. This method, since introduced, has been widely applied to economic and financial market analyses (Bhargava 1986, Durlauf and Phillips 1988).

FLUCTUATIONS IN TIMBER PRICES

Fluctuations in timber prices are examined in this section. First, variances of selected timber prices are computed and compared with one another. Then, we investigate whether the selected timber prices follow a random walk.

(a) Means, Standard Deviations, and Growth Rates of Selected Timber Prices — The timber prices examined in this paper include (1) sawtimber stumpage prices of Douglas-fir, southern pine, ponderosa pine, western hemlock, eastern hardwoods, and oaks; (2) sawlog prices of Douglas-fir, southern pine, and oaks; and (3) veneer log prices of Douglas-fir, black walnut, and white

Table 1.—Means, standard deviations, and growth rates of selected real timber prices, from 1950 to 1986

Species	Mean (1967 $)	Standard deviation (1967 $)	Growth rate (%)
		Sawtimber Stumpage Prices	
Douglas-fir	69.55	41.17	3.95
Southern pine	43.52	12.10	1.07
Ponderosa pine	42.29	23.82	2.70
Western hemlock	33.11	22.76	4.68
Eastern hardwoods	23.19	4.26	0.50
Oaks	24.84	7.80	2.11
		Sawlog Prices	
Douglas-fir	87.22	29.04	2.58
Southern pine	67.40	14.51	1.41
Oaks	44.31	4.65	1.02
		Veneer Log Prices	
Douglas-fir	166.76	175.29	1.00
Black walnut	549.85	220.80	3.73
White oak	226.91	131.97	5.25
		Stock Price	
Dow Jones Industrial Average (DJIA)	798.80	340.24	3.77

oaks. The prices used for this analysis are the real annual prices measured in 1967 dollars for the time period from 1950 to 1986 (Ulrich 1987).

Means, standard deviations, and growth rates of the selected timber prices are presented in Table 1. For stumpage prices, Douglas-fir has the highest standard deviation and mean, and oaks and eastern hardwoods have the lowest standard deviations and means. In terms of sawlog prices, Douglas-fir has the highest standard deviation and mean, and oaks have the lowest standard deviation and mean. For veneer log prices, black walnut has the highest standard deviation and mean, and white oak has the lowest standard deviation. All the selected real timber prices increased during the time period from 1950 to 1986. The price growth rate (λ) is calculated using the following formula:

$$P_t = P_o e^{\lambda t}$$

Taking the natural logarithm of the formula, we have $\ln P_t = \ln P_o + \lambda t$
This is a linear equation. Using regression analysis, we can estimate the price growth rate (λ).

The growth rates of the selected real timber prices range from 0.5% for the sawtimber stumpage price of all eastern hardwoods to 5.25% for the veneer log price of white oak (Table 1). The growth rate of the real Dow Jones Industrial Average (DJIA) for the same period was 3.77% with a mean of 798.80 and a standard deviation of 340.24. From 1950 to 1986, the price growth rate of black walnut veneer logs was about the same as that of the real DJIA, and the prices of white oak veneer logs appreciated much more than the real DJIA, while the standard deviations of the timber prices of these two species were smaller than that of the real DJIA. This implies that the timber prices for black walnut and oak are less volatile than the real DJIA and increase at least as fast as the real DJIA.

(b) Unit Root Tests of Selected Timber Prices — Two unit root tests were conducted to determine whether a particular timber price series is predictable or follows a random walk. One (using ϕ_2 statistic) tests whether a timber price series follows a random walk without a drift. The other (using ϕ_3 statistic) tests whether a timber price series follows a random walk with a drift. Calculated values of ϕ_2 and ϕ_3 are shown in Table 2.

Table 2. Calculated values of unit root test statistics for selected timber prices

Species	Φ_2 (without drift)	Φ_3 (with drift)
	Sawtimber Stumpage Prices	
Douglas-fir	2.5	3.6
Southern pine	6.4**	9.4**
Ponderosa pine	2.9	4.1
Western hemlock	1,337.5***	1,932.0***
Eastern hardwoods	21,428.5***	30,954.0***
Oaks	10,222.3***	14,770.6***
	Sawlog Prices	
Douglas-fir	3.4	4.8
Southern pine	5,947.0***	8,633.7***
Oaks	77,476.2***	112,354.2***
	Veneer Log Prices	
Douglas-fir	5.7*	8.5**
Black walnut	64.7***	91.5***
White oak	311.2***	445.9***

* Rejects the null hypothesis that the timber price follows a random walk at a 5% level.
** Rejects the null hypothesis that the timber price follows a random walk at a 2.5% level.
*** Rejects the null hypothesis that the timber price follows a random walk at a 1% level.

The unit root testing results indicate that prices of the selected hardwoods including black walnut and oaks do not follow a random walk, whereas the prices of some softwoods, particularly the stumpage and sawlog prices of Douglas-fir, seem to follow a random walk. This implies the prices of black walnut and oaks are predictable, i.e., black walnut and oak production is less risky in terms of price fluctuations when compared with some softwood species such as Douglas-fir. According to the means and growth rates of the prices, black walnut and oak plantations managed for the production of veneer logs seem to yield higher economic returns than other timber species. However, the standard deviations of the timber prices indicate that black walnut plantations are more risky than softwood timber species while oak plantations appear to be less risky than other timber species.

BLACK WALNUT AND RED OAK PLANTATIONS

Timber prices of black walnut and red oak are quite attractive. As shown in Table 1, the growth rates of the real veneer log prices of these two species exceed other species. However, like other timber species, some uncertainties and risks are inevitable in black walnut and oak plantations. Table 1 also shows that the standard deviation of the black walnut veneer log price is higher than any other species, whereas the standard deviations of the oak timber prices are lower than all the other species except for the eastern hardwoods.

In this section, the sensitivity of the Present Net Values of hypothetical black walnut and red oak plantations to changes in timber prices and the discount rate is examined. The hypothetical plantations include five different compositions of the two species: (1) pure (100%) black walnut (BW100), (2) 75% black walnut and 25% red oaks (BW75), (3) 50% black walnut and 50% red oaks (BW50), (4) 25% black walnut and 75% red oaks (BW25), and (5) pure (100%) red oaks (RO100). The plantations are assumed to be established on a site index of 65 with a 12 x12 ft spacing. The rotation length for these plantations is assumed to be 60 years in order to limit the number of simulations and focus on the impact of changes in timber prices and the discount rate on the economic returns.

Management practices for the plantations include site preparation, planting, chemical weed controls for the first 3 years, corrective and clear-length pruning, and thinning at ages 15, 30, and 45. These management practices are designed according to Thompson (1976), Burde (1988), and Clark and Hutchinson (1989). The costs for the management practices are estimated according to several sources (Hilliker *et al.* 1969, Olson *et al.* 1978, Kincaid *et al.* 1982, Winebar and Gunter 1984, Garret *et al.* 1986, Noweg and Kurtz 1987, Straka *et al.* 1988). Taxes and land rent are excluded from the analysis.

(a) Impacts of Changes in Timber Prices — Figures 1 and 2 show economic returns, measured in annual equivalent revenue (AER) and benefit-cost ratio respectively, which can be generated from black walnut and red oak plantations at various stumpage price levels and a 4% real discount rate. The annual equivalent revenue and benefit-cost ratio at a given discount rate appear to be positively and linearly related to the stumpage price. The economic returns of the black walnut plantations are higher than those of the red oak plantations. However, the higher the proportion of black walnut in the mixed black

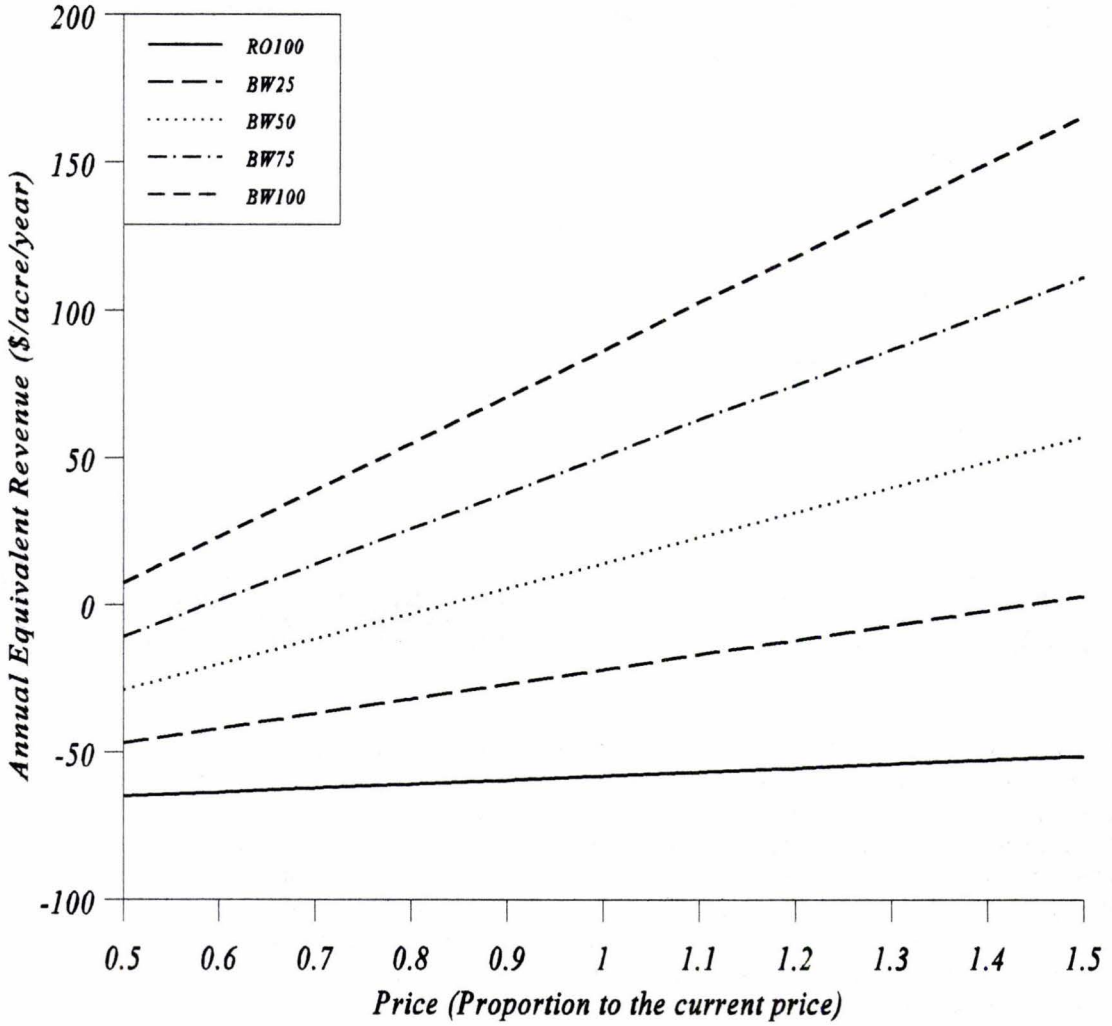

Figure 1.—The relationship between annual equivalent revenue and stumpage price at a 4% real discount rate.

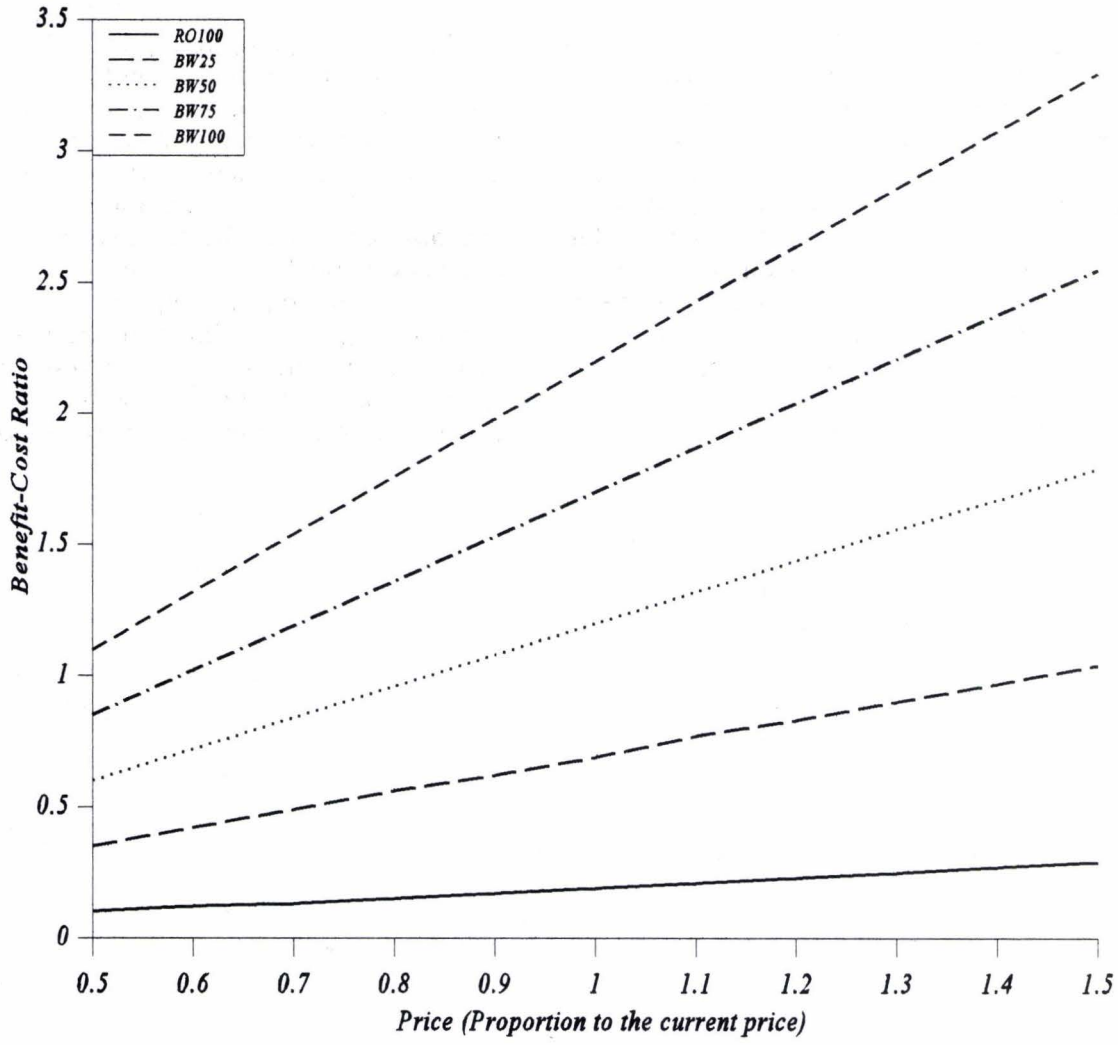

Figure 2.—The relationship between benefit-cost ratio and stumpage price at a 4% real discount rate.

walnut and red oak plantations, the more sensitive the annual equivalent revenue and benefit-cost ratio to a change in the stumpage price. Using a 4% real discount rate and current average timber prices for black walnut and red oaks, only the plantations with 50% or more black walnut will produce a positive economic return or have a benefit-cost ratio greater than 1. The pure red oak plantation will not be profitable even if its current timber price increases by 50%. If the current timber price decreases by 50%, only the pure black walnut plantation will generate a positive profit or have a benefit-cost ratio greater than 1 at a 4% real discount rate.

The internal rate of return which can be generated from black walnut and red oak plantations at various stumpage price levels is shown in Figure 3. At the current timber price level, all the black walnut and red oak plantations except the pure red oak plantation will produce a positive internal rate of return with the highest equal to 5.77% for the pure black walnut plantation. However, the marginal effects of stumpage price changes on internal rate of return are quite significant, particularly at low stumpage prices.

(b) Impacts of Changes in Discount Rate — Economic returns of black walnut and red oak plantations are very sensitive to changes in the

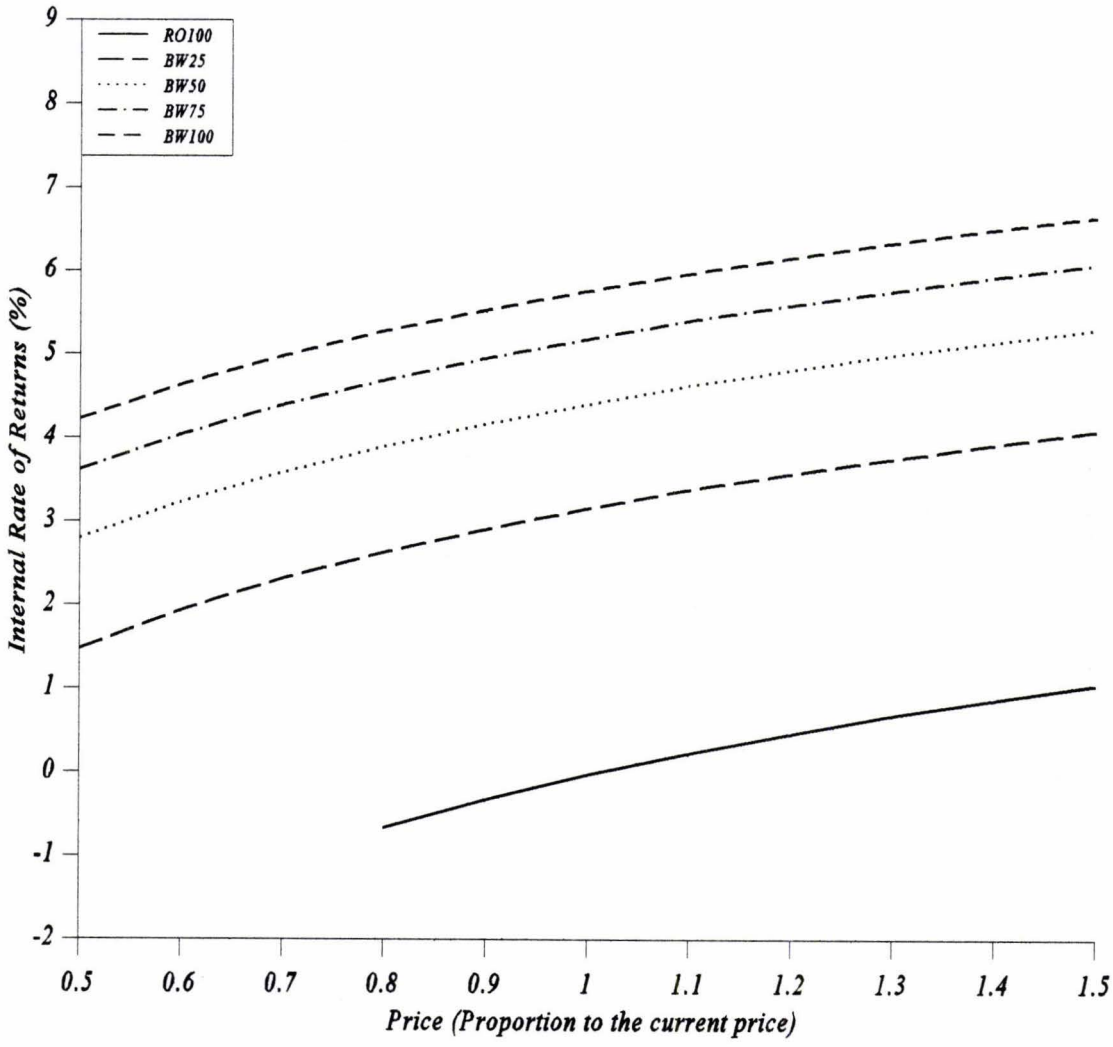

Figure 3.—The relationship between internal rate of return and stumpage price.

discount rate, particularly at low discount rates. Figure 4 shows the diminishing impacts of discount rate on annual equivalent revenue and the higher sensitivity of economic returns to discount rate changes from black walnut plantations than from red oak plantations. The pattern of the relationship between benefit-cost ratio and discount rate (Figure 5) is similar to that between annual equivalent revenue and discount rate. At a 4% real discount rate and the current timber price level, only the plantations with more than 50% black walnut composition will produce a positive profit (a positive AER or a benefit-cost ratio greater than 1). If the real discount rate is greater than 6% per year, none of these plantations will be profitable at the current timber prices for black walnut and red oak.

CONCLUSIONS

The standard deviations of the real timber prices from 1950 to 1986 indicate that the timber price for black walnut is more volatile, while the timber price for oaks is less volatile than softwood timber prices. The mean prices and price growth rates of black walnut and oak veneer logs are considerably higher than those of Douglas-fir. According to the unit root tests, the timber prices for black walnut and oak appear to be predictable. Also, based on simulation results, the economic returns of black walnut plantations are more sensitive to changes in the timber price and the discount rate than those of red oak plantations. Overall, compared to softwood timber species, black walnut and red oak plantations

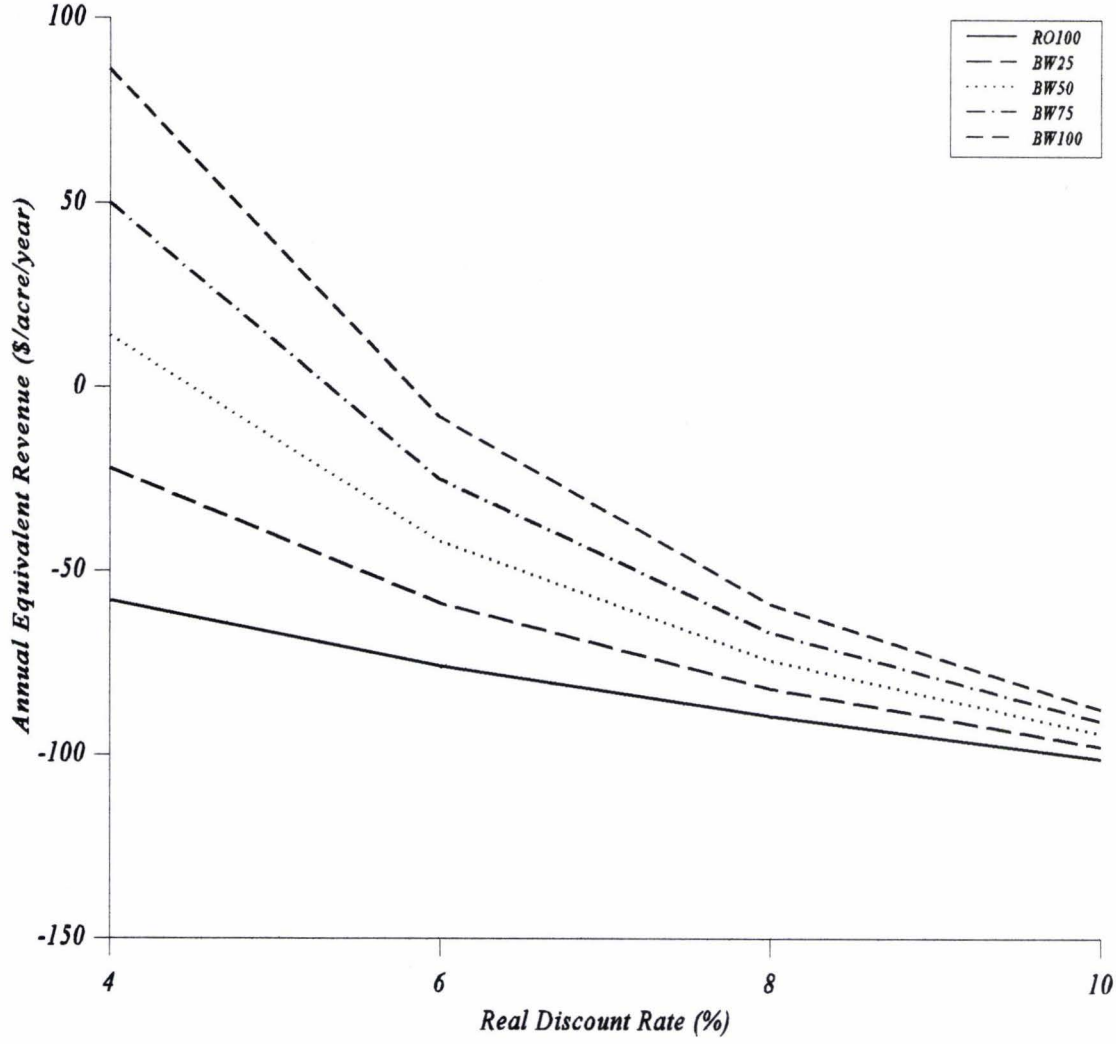

Figure 4.—The relationship between annual equivalent revenue and real discount rate.

have higher economic returns, and black walnut plantations are more risky while red oak plantations are less risky.

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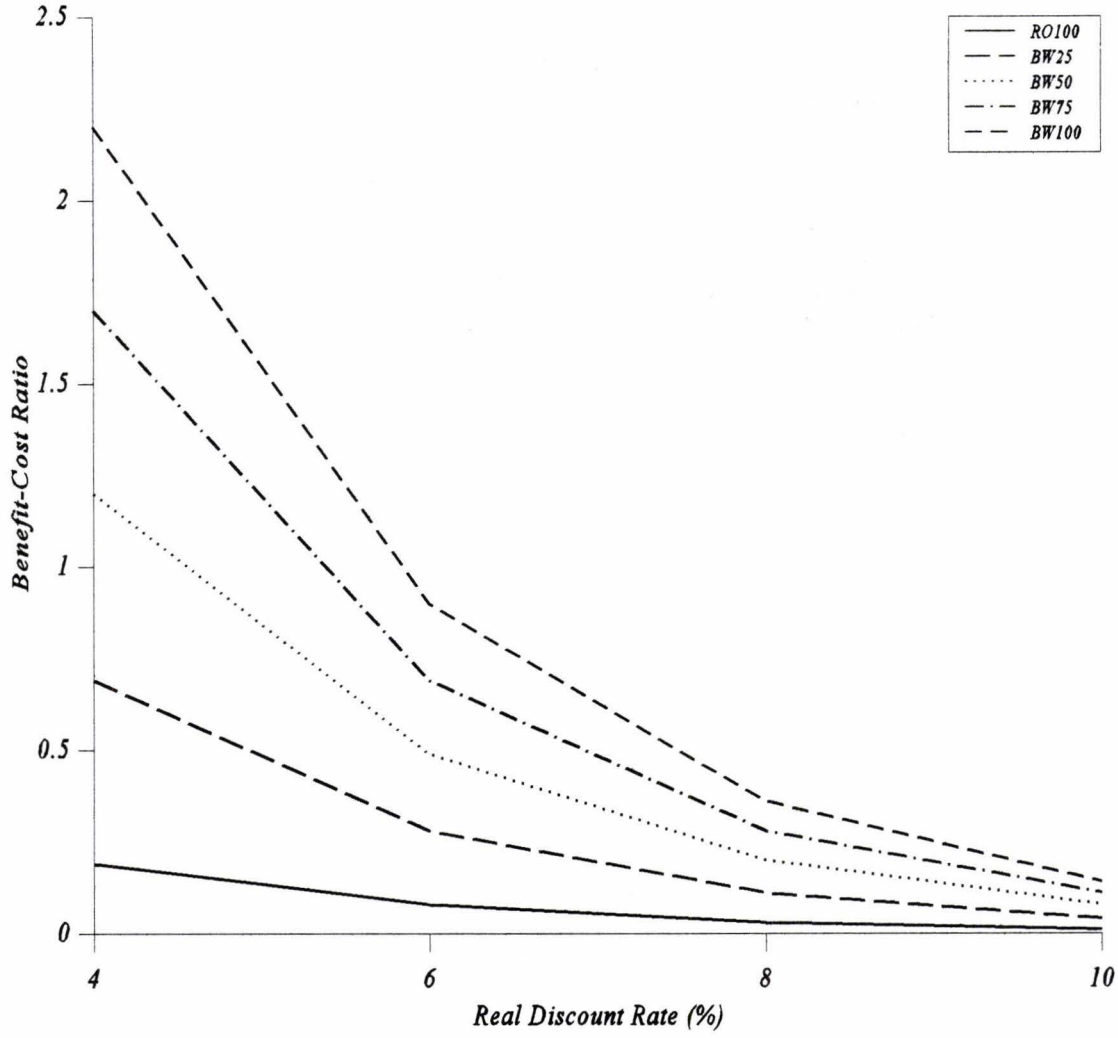

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INCENTIVES FOR PLANTING BLACK WALNUT

Lester R. Pinkerton and Robert J. Moulton[1]

ABSTRACT.—Usually the interest in timber production increases as the number of acres owned increases. However, interest in black walnut planting is more broad based and landowners of both small and large acres realize the multiple benefits of black walnut. The economic potential of black walnut has always aroused the interest in private landowners. Forest landowners have responded to the encouragement by the federal government cost-share programs, and tax benefits to expand and improve their walnut resource. Some states also offer their own cost-share or tax incentive programs to help and encourage landowners to plant or manage black walnut. Agency responsibility for some federal programs was shifted in 1995 and some programs were changed by the 1996 Farm Bill. The programs offered in 1996 were Agricultural Conservation Program (ACP), Forestry Incentives Program (FIP), Stewardship Incentive Program (SIP), Wetland Reserve Program (WRP), and Conservation Reserve Program (CRP). Starting in FY 1997 ACP will be combined with several other programs to form the Environmental Quality Incentives Program (EQIP).

INCENTIVES

INCREASED FINANCIAL NEED

Nonindustrial private forest lands (NIPF) have been very productive for many years, and these lands are becoming more important to the nation's timber supply each year. Timber harvest from public forest have diminished in recent years for several reasons. The spotted owl controversy made the headlines, but other environmental issues and policy changes have also reduced the timber harvested from federal lands. Therefore, private forest lands must supply more of the timber for the nation. Projecting the effect on the demand for walnut is difficult. However, timber demand is projected to increase continuously both domestically and internationally (Gaddis *et al.* 1995).

Increased pressure on NIPF to provide the needed timber supply is also resulting in more local regulations. State and local regulation of private forest practices has increased dramatically over the last 10 years (Greene and Siegel 1994). The increased harvest pressure and more regulations may increase the need to provide landowner forestry incentives. However, changes in the national programs may have the opposite effect and reduce the options for cost-share incentives for the landowner.

Financial incentives for forest management have been available to landowners for more than 50 years. The incentive is usually through a cost-share program, but may also be as tax credits or deductions. Cost-share programs may seem confusing to some landowners, but all the programs are voluntary, provide financial assistance, provide technical assistance, and landowners are responsible for proper installation of the practice (Moulton 1994). Walnut growers and other nonindustrial private forest (NIPF) landowners have used the encouragement by the federal government cost-share programs to expand and improve their forest resource. Some

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states also offer their own cost-share or tax incentive programs to help and encourage landowners to plant or manage their forest land.

PRIVATE FOREST LANDOWNERS

Landowner motivation for planting black walnut or other tree species is usually based on an interest in conservation. A 1994 survey of private forest landowners of the U.S. shows that more than 90% of the NIPF landowners own less than 100 acres of forest-land. Only 3% say they are holding their land primarily for timber production, but they control only 29% of the private forest land (Birch 1995). However, many of these landowners will harvest timber in the next 10 years. Approximately 67% of the hardwoods harvested in the U.S. come from NIPF lands.

Generally, interest in timber production increases as the number of acres owned increases. However, interest in black walnut planting is broad based and landowners of both small and large acres realize the multiple benefits of black walnut. Timber production, wildlife habitat improvement, and increased value of the land provide additional incentives for landowners to plant black walnut or manage their existing walnut resource.

The rapidly rising prices (not considering inflation) for black walnut logs over the last 30 years, combined with growing awareness of the scarcity of black walnut timber stimulated in some landowners an increased interest in planting black walnut trees (Chenoweth 1995). It is true that cost-share programs have played a major role in promoting black walnut planting and timber stand improvement; however, the reputation of black walnut as a valuable hardwood has resulted in many acres being planted without cost-share.

Information from the 1994 survey of forest-land owners provides a good look at the insight and attitudes of these important landowners. The study showed a large turnover of land ownership with 40% of the land acquired since 1978. The survey also showed that only 5% of the owners have a written forest management plan. The percentage of walnut growers is probably greater than 5%, but no data are available to show if this is true. The large percentage of land turnover emphasizes the need for a forest management plan. Even if cost-share dollars are not used, technical assistance (plan development) is very beneficial to the landowner. Many landowners also realize that they could benefit from increased land value, or encourage potential buyers if a managed black walnut stand is part of the sale.

COST-SHARE PROGRAMS

The 1996 Farm Bill was very controversial, but changes in the cost-share programs were not as great as expected. Some existing programs were changed, and several programs were combined to form a new program. The Conservation Consolidation and Regulatory Reform Act (H.R. 2542) of the Conservation Title of the Farm Bill, was not passed. The bill would have combined the Forestry Incentives Program (FIP), Stewardship Incentive Program (SIP), and the Forest Legacy Program and other agricultural assistance programs.

FORESTRY INCENTIVES PROGRAM

The Forestry Incentives Program (FIP) is a reforestation and timber management cost-share program authorized in 1974. The accomplishments of the program and the economic evaluations of its activity show that it has been successful at increasing forest planting and improvement practices. FIP is also economically efficient (Gaddis *et al.* 1995). Until recently FIP was available through the Farm Service Agency (FSA), but was transferred to the Natural Resource Conservation Service (NRCS) in July of 1995. Under the 1990 Farm Bill, FIP was scheduled to end on December 31, 1995. However, the program was extended by Congress until 2002 in the 1996 Farm Bill.

FIP funds are allocated to the states based on eligible forest acreage, ownership patterns, growth potential and accomplishments. The minimum acreage for FIP practices is 10 acres. The 10-acre minimum has been a problem in some states where smaller acreage is desirable for walnut production, and is difficult to farm. Many of these small acreage have seeded to less desirable species. If a cost-share program had been available for planting black walnut, some of the small areas may have been planted to walnut after harvest.

Only timber sites capable of producing at least 50 cubic feet of wood per acre per year are eligible for FIP. In some states only certain counties are designated as eligible for the program. Landowners must not own more than 1,000 acres of forest land to be eligible. The current national standard allows cost-share rates up to 65% of total cost to complete the practice. State rates have varied from 50 to 75% since 1994. States have the authority to set their rates below the national rate, but cannot exceed the 65%.

The cost-share payment to a landowner is limited to $10,000 per year. Long-term agreements (LTA's) are allowed on projects more than 40 acres in size. The LTA allows a landowner to complete tree planting and timber stand improvement over a 3 to 10 year period. The landowner is still limited to $10,000 per year, but it allows the completion of the practices without having to reapply for a new contract each year.

The practices must be maintained for a minimum of 10 years. The technical responsibility for FIP practices is assigned to the USDA Forest Service that delegates the responsibility to the State Forestry Agency in each state. A forest management plan is required to be eligible for FIP, but the plan requirements are much less than the guidelines for Forest Stewardship Plans. The plan is usually prepared by the Service Forester with the State Forestry Agency.

STEWARDSHIP INCENTIVE PROGRAM

The Stewardship Incentive Program (SIP), established by the 1990 Farm Bill, authorized the federal government to provide up to 75% cost-shares to complete various practices identified in a Landowner Forest Stewardship Plan. The plan must be developed by a professional natural resource manager. The program must follow national guidelines, but allows greater flexibility for the states to develop the program to fit the needs of the state. The state program must be consistent with the SIP National Standards and Guidelines, but the flexibility has made the program very desirable. Funding for the program was first available in FY 1992.

The following practices are approved for SIP cost-share:

- SIP-1 Landowner Forest Stewardship Plan Development
- SIP-2 Reforestation and Afforestation
- SIP-3 Forest Improvement (thinning, pruning, crop tree release, and vine removal)
- SIP-4 Agroforestry Establishment, Maintenance and Renovation
- SIP-5 Soil and Water Protection and Improvement
- SIP-6 Riparian and Wetland Protection and Improvement
- SIP-7 Fisheries Habitat Enhancement
- SIP-8 Wildlife Habitat Enhancement
- SIP-9 Forest Recreation Enhancement

The State Forester has the authority to decide which practices are offered and the specifications for each program practice allowed in the State within national guidelines. These specifications may not be less restrictive than the national-level practices.

The cost-share is available to landowners that own 1,000 acres of forest land or less. An application for an exemption up to 5,000 acres may be made through the State Forester. SIP has no timber productivity standard like FIP. Cost-share funding is limited to $10,000 per year per landowner.

A cost-share rate up to 75% is allowed, but the State may set a lower rate for all or part of the practices. The States also set the priority for each practice. Sign up for SIP is through the county FSA office, but the State Forester is the administrator of the program. The 1990 Farm Bill mandates that each State establish a Forest Stewardship Coordinating Committee with representatives from State, and Federal agencies, environmental organizations, consulting foresters, forest industry, landowners and other appropriate individuals. The committee advises the State Forester on the administration of SIP for the State.

SIP requires no minimum acreage for landowners to qualify. States are allowed to set their own minimum, but it cannot be greater than 25 acres. Allowing less than 10 acres has benefited walnut growers that were not eligible for FIP in some states.

AGRICULTURAL CONSERVATION PROGRAM

The Agricultural Conservation Program (ACP) is a farm program authorized in 1936, and is designed to encourage resource conservation practices. The program includes forestry practices, but the intent is conservation and not timber production. Cost-share assistance is available for tree planting, timbers stand improvement, site preparation for natural regeneration, and wildlife habitat improvement.

The funds available for forestry practices in most states are not sufficient to meet the need. Funding for ACP was reduced by 50% beginning with FY 1995, and was further reduced for FY 1996. Reduced funding has resulted in reduced cost-share rates from the 75% maximum allowed nationally, and the elimination of low priority practices. ACP is available to all landowners despite ownership size, but cost-share is limited to $3,500 annually.

ACP is administered by FSA, but the technical responsibility for ACP forestry practices is assigned to the State Forester. ACP forestry practices must be maintained for a minimum of 10 years.

The 1996 Farm Bill combines ACP with the Water Quality Incentives Program, Great Plains Conservation Program, and the Colorado River Basin Salinity Control Program into a new program called Environmental Quality Incentives Program (EQIP).

The guidelines for EQIP are not known at the time this paper was prepared. The Farm Service Agency has suggested that forest land in not eligible for funding under EQIP. However, efforts are under way to have tree planting and timber stand improvement included as approved practices. It appears that each state committee must rank all the practices on environmental benefits and costs. Practices will be approved based on their ranking. Tree planting could continue, as in the past, on agricultural land to address environmental problems, such as soil erosion and to improve water quality. However, 50% of the program funds are to assist crop and livestock producers deal with environmental and conservation improvements. Limited funds will increase competition at the county level, and tree planting will probably be reduced from previous years.

CONSERVATION RESERVE PROGRAM

The Conservation Reserve Program (CRP) was established by the 1985 Farm Bill. Its purpose was to remove 45 million acres of highly erodible cropland from agricultural production. Program goals included the reduction of erosion, protection of the long-term productivity of the land, water quality improvement, enhancement of wildlife, reduction of sedimentation, reduction of surplus commodities, and income support for farmers (Osborn *et al.* 1992). Landowners with CRP contracts are required to establish permanent vegetative cover on the land, and in return are paid annual rental payments. CRP provides landowners up to 50% cost-sharing for practice installation and an annual rental payment during the 10-year contract. Contract period for hardwood trees are 15 years. Maximum payment is $50,000 annually per landowner.

The tree planting practice (CP-3) is designed to establish a stand of trees that will provide multipurpose forest benefits, control excessive erosion and reduce water, air or land pollution (Adams 1989). Landowners that signed up for grass (CP-1) may convert to trees (CP-3A).

Walnut trees can also be planted under the filter strip/riparian buffer practice (CP-13D) designed to establish trees immediately next to streams, lakes and other bodies of water. These are usually the more productive sites and may be well suited for walnut planting.

The only CRP Sign up in 1995 was held in September. Landowner bids competed on a national basis rather than just landowners' bid within their own State. Riparian areas were emphasized by offering a 10% incentive payment for riparian buffer filter strips.

High feed grain prices in 1995 and 1996 may be a major factor in the decision of many landowners to take CRP acres out of the program. However, new acres signed up are more likely to include tree planting than in previous sign ups.

WETLAND RESERVE PROGRAM (WRP)

The WRP was authorized in 1990 to give private landowners cost-share funds to restore previously converted wetlands to wetland status, and to protect wetlands. The cost-share is 50 to 100% of the restoration costs, depending on the

length of the easement. WRP is not used much for walnut planting, but some sites may be suitable for walnut. WRP has been extended through 2002.

BLACK WALNUT PLANTING

Learning the real impact of incentive programs on the planting and management of black walnut is difficult. Johnson (1995) summarized results of a computer search by Jeralyn Snellgrove of the U.S. Forest Service of walnuts planted under each program for the years 1987 to 1995. The results represents only walnut trees planted during the 1987-1995 period with cost-share programs (Table 1); however, it does give a good comparison of the planting accomplished under each program. The data were obtained through the Conservation Reporting and Evaluation System (CRES) data base.

Table 1.—Black walnut trees planted by program from 1987 to 1995

Program	No. of States	Acres of trees planted
FIP	14	1,580
ACP	24	7,449
CRP	16	10,990
SIP	20	2,010

CRP has encouraged more walnut planting than any other federal cost-share program (Johnson 1995). More acres of walnut have already been planted under SIP than planted with FIP cost-share. However, it is well documented that FIP is more oriented to large softwood plantings.

STATE PROGRAMS

Some states provide cost-share incentives for planting and managing trees besides the federal programs. A recent survey showed that states within the black walnut range that provide financial incentives include: Illinois, Indiana, Iowa, Maryland, Missouri, Nebraska, Virginia, North Carolina, and South Carolina.

TAX CREDITS AND DEDUCTIONS

REFORESTATION TAX CREDIT

Landowners may claim a 10% investment tax credit (an offset against taxes owed) up to $10,000 of qualifying reforestation expenses annually on their federal income tax. Qualifying expenses include the direct cost of establishing a stand of timber. Cost-share funds may also be included if reported as income. If treated as income, cost-share funds may be expensed on the same tax return.

AMORTIZATION

Landowners may also deduct reforestation expenses incurred in any 1 year from gross income from other sources over 8 tax years. If the taxpayer takes the 10% tax credit, the amount that may be amortized is 95% of reforestation cost. A depreciation of 1/14 on the first and eighth years and 1/7 each of the other 6 years is allowed.

CAPITAL GAINS

For most forest landowners, a timber sale is not a common occurrence. However, when a sale does occur, important tax considerations should influence management record keeping and reporting. Standing timber held for more than one year is a capital asset, and income generated from its sale is a long-term capital gain (Jones 1989). The capital gain exclusion was eliminated by the 1986 Tax Reform Act, but maintaining capital gains status for capital loss is still important for self employment tax exclusion, and possible changes in the future tax code (Jones 1989).

COST-SHARE PAYMENTS

Cost-share payments may generally be excluded from gross income, at the taxpayer's option. However, the excludable portion does not qualify for the investment tax credit and amortization. If cost-share payments under SIP, FIP and ACP are counted as gross income, they qualify for investment tax credit and amortization. An individual's tax situation will determine which is the best decision for them. Many cost-share payments made by states need to be handled on federal tax returns in the manner just described.

STATE TAX INCENTIVES

The states of Illinois, Indiana, Michigan, Minnesota, Missouri, New York, North Carolina, Ohio, South Carolina, Tennessee, Virginia, and West Virginia provide some tax incentive for owning forest land. Incentives vary by state and range from property tax reduction for forest land to capital gain advantage for timber sold.

SUMMARY

Most landowners have access to technical assistance for planting and managing black walnut through their state forestry agency or private consultants. Most likely technical assistance will continue to be available. Cost-share programs will continue to be available, but some of the guidelines will change. There will probably continue to be efforts in Congress to combine all the programs into one, or at least reduce the number of programs by combining programs. More states will probably offer cost-share programs, especially if the federal funding of the programs continues to decline.

Landowners want to be good forest stewards, but the present tax codes discourage the long term investment in forest management. Changes in the tax policy need to be simple and easy to understand so the small NIPF landowner can benefit from the changes. Efforts to make these changes will continue.

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APPENDIX I: METRIC TO ENGLISH CONVERSIONS

Convert from	To	Multiply by
bar (10^6 dynes/cm^2)	pound/inch^2 (psi)	14.5
bar (bar)	atmosphere (atm)	0.9869
calorie	British thermal units (Btu)	0.00397
Celsius ©	Fahrenheit (F)	1.80C + 32
centimeter (cm)	inch (in)	0.394
gram (g)	ounces (oz)	0.0353
hectare (ha)	acre	2.471
kilogram (kg)	pound (lb)	2.205
kilograms/hectare (kg/ha)	pound/acre	0.892
kilometer (km)	mile (mi)	0.621
kilometer^2 (km^2)	mile^2 (mi^2)	0.386
kilometer^2 (km^2)	acre	247.1
liter (L)	quarts (qt)	1.057
lux (lx)	candle-foot^2 (ft-c)	0.0929
meter (m)	yard (yd)	1.094
meter (m)	feet (ft)	3.281
meter^2 (m^2)	feet^2 (ft^2)	10.76
millimeter (mm)	inch (in)	0.0394
ton (t)	ton	1.102

Notes

The United States Department of Agriculture (USDA) prohibits discrimination in its programs on the basis of race, color, national origin, sex, religion, age, disability, political beliefs, and marital or familial status. (Not all prohibited bases apply to all programs.) Persons with disabilities who require alternative means of communication of program information (braille, large print, audiotape, etc.) should contact the USDA Office of Communications at (202) 720-2791.

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*U.S. Government Printing Office: 1997 - 556-827

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Proceedings of the Fifth Black Walnut Symposium held 28-31 July 1996 in Springfield, Missouri. Includes 46 manuscripts and abstracts dealing with establishment, management, and utilization of black walnut with emphasis on increased use for agroforestry and nut culture.

KEY WORDS: *Juglans nigra* L., plantation culture, nut culture, agroforestry.

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Our job at the North Central Forest Experiment Station is discovering and creating new knowledge and technology in the field of natural resources and conveying this information to the people who can use it. As a new generation of forests emerges in our region, managers are confronted with two unique challenges: (1) Dealing with the great diversity in composition, quality, and ownership of the forests, and (2) Reconciling the conflicting demands of the people who use them. Helping the forest manager meet these challenges while protecting the environment is what research at North Central is all about.